Date of Publication:
February 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

The Australian paintings of Marianne North, 1880–1881: landscapes '*doomed shortly to disappear*'

John Leslie Dowe

Australian Tropical Herbarium, James Cook University, Smithfield, Qld 4878 AUSTRALIA.
john.dowe@jcu.edu.au

Abstract: The 80 paintings of Australian flora, fauna and landscapes by English artist Marianne North (1830-1890), completed during her travels in 1880–1881, provide a record of the Australian environment rarely presented by artists at that time. In the words of her mentor Sir Joseph Dalton Hooker, director of Kew Gardens, North's objective was to capture landscapes that were 'doomed shortly to disappear before the axe and the forest fires, the plough and the flock, or the ever advancing settler or colonist'. In addition to her paintings, North wrote books recollecting her travels, in which she presented her observations and explained the relevance of her paintings, within the principles of a 'Darwinian vision,' and inevitable and rapid environmental change. By examining her paintings and writings together, North's works provide a documented narrative of the state of the Australian environment in the late nineteenth-century, filtered through the themes of personal botanical discovery, colonial expansion and British imperialism.

***Cunninghamia* (2020) 20: 001–033**
doi: 10.7751/cunninghamia.2020.20.001

© 2020 Royal Botanic Gardens and Domain Trust

Introduction

The Marianne North Gallery in the Royal Botanic Gardens Kew houses 832 oil paintings which Marianne North (b. 24 Oct. 1830, Hastings, England; d. 30 Aug. 1890, Alderley, England) **(Fig. 1)** completed during her world travels between 1871 and 1884. The paintings are more or less hung abutted to each other, and occupy all the available space on the gallery walls **(Fig. 2)**. The display also includes illustrated panels, doors and architraves that she completed, and a collection of 246 samples of polished timber arranged vertically below the paintings. The gallery, reminiscent of a Greek temple, was funded wholly by North, and designed in collaboration with the architectural historian James Fergusson (1808–1886), and was first opened in 1882 (Hemsley 1881; Anon. 1882).[1] With the completion of more paintings during subsequent excursions there was the need for additional space (Anon. 1883). An extension to the gallery was constructed and the present exhibition of 832 paintings, almost her entire life's output, was finalised in 1885 (Hemsley 1885). The arrangement of the paintings in geographical groupings remains as North personally installed them. North's travels took her to five continents and 17 countries, including Canada, United States and Jamaica (1871–72); Brazil (1872–73); Teneriffe, Japan and United States (1875); Singapore, Indonesia and Sri Lanka (1876); India (1877–79); Singapore, Indonesia, Australia, New Zealand and the United States (1880–81); South Africa (1882); Seychelles (1883); and Chile (1884).

Fig. 1. Marianne North, date not known, reproduced from the frontispiece of *Some Further Recollections of a Happy Life, Selected from the Journals of Marianne North Chiefly Between the Years 1859 and 1869*. James Cook University Library.

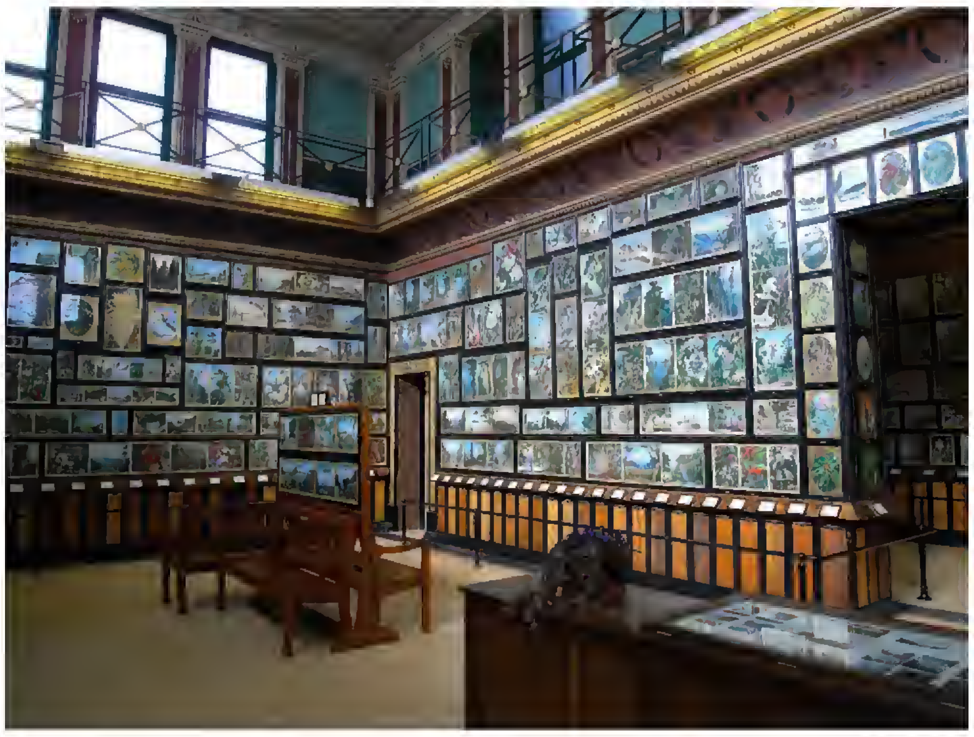


Fig. 2. Interior of the Marianne North Gallery, Royal Botanic Gardens Kew. Photo: M. McDonald.

The exhibition mainly includes paintings of plants but also scenes of many of the places she visited. The original catalogue was sub-titled 'plants and their homes' and it was estimated that over 1000 species were represented in the paintings thus providing a sampling of the more distinctive aspects of the world's flora (Hemsley 1882; Anon. 1914). Although the catalogues were funded and supervised by North, identification of the species was provided by the botanists then at Kew Gardens, in particular, William Botting Hemsley, Daniel Oliver, John Gilbert Baker and John Reader Jackson (Anon. 1882).

In addition to her paintings and gallery, North, in later years, worked on what was intended to be a book that detailed her journeys and experiences. However it remained unpublished at the time of her death in 1890; the manuscripts were edited by her sister Catherine Symonds (*née* North) (as Mrs John Addington Symonds), and published as three separate books: *Recollections of a Happy Life Being the Autobiography of Marianne North* in two volumes first published in 1892 and reprinted in 1893 with minor corrections (North 1892, 1893a); and *Some Further Recollections of a Happy Life, Selected from the Journals of Marianne North Chiefly Between the Years 1859 and 1869* first published in 1893 (North 1893b). All were successful publications going into a number of editions and reprints. Many of her paintings are described or alluded to in her books, thus making a clear connection between her travel discourses and the relevance of the plants and scenes that she depicted.

Stimulated by her unique life and public persona, North is one of the most studied women travellers and artists of the Victorian era, with numerous books and papers, both scholarly and non-academic, and a number of theses devoted to her life history, activities and creative works (Middleton 1965; Haller 2009). Some research on her has been framed within such broad topics as Victorian values, British imperialist aspirations, gender identity and philosophy (Losano 1997; Carroll 2018). A number of authors have interpreted her writings as a manifestation of the prejudices of imperial conquest, privilege acquired by wealth, and the supposed superiority of the British peoples (Losano 1997; Anderson

---

[1] *Recollections of a Happy Life*, vol. 2, p. 338.

2003). This present work provides the first investigation of her Australian paintings in a broadly interpreted botanical and ecological perspective.

North's father, Frederick North (1800–1869), was descended from a line of influential and wealthy landowners. He was Cambridge-educated and the occasional Liberal Member of Parliament for Hastings. North's mother died when North was 25 years old, thus leaving her, as the eldest unmarried daughter, to manage the household and to care for her father. North always wrote reverentially of her father (but disparagingly of her mother), and upon his death in 1869 she pledged to pursue a life devoted to the scientific education of the English public through her art as she thought most people were 'woefully ignorant of natural history' (Agnew 2011; Watts 2017).[2] Among a plethora of influential men and women, the family's circle of friends included the Kew Garden botanists George Bentham and William and Joseph Hooker whom Marianne engaged both socially and in connection with botanical questions; the naturalist Charles Darwin who encouraged her to visit Australia; the anthropologist, geographer and naturalist Francis Galton who remained one of her closest friends;[3] the geophysicist, explorer and naturalist Sir Edward Sabine, a long-time family friend;[4] the physicist John Tyndall, also a long-time family friend;[5] the artist Robert Dowling who provided a number of painting lessons when he resided with the Norths; the author Elizabeth Gaskell who moved to Hastings to write her last book;[6] and the artist and author Edward Lear who also lived nearby.[7] Biographical aspects of North's life can be found in a number of publications, including Anon. (1890, 1914), Moon (1980), Vellacott (1986), O'Connor (1997) and Payne (2016).

Marianne North's place in botanical art and botany

North's historical position in art and botany is ambiguous and does not fall clearly into either category (Sheffield 2001; Gladston 2012). She had some formal training in art and apparently none in botany (Carroll 2018), but had a natural talent for music and illustration, and a family intellectual tradition that encouraged her to interact with leaders in science then active in Britain. Botanical art historians have been dismissive of her style and technique (Blunt & Stearn 1971). Being untrained in the rigors of professional botany, her status as an amateur botanist excuses her to be taken overly seriously in her botanical pursuits with regard to nomenclature and descriptions. She often used common names rather than the botanical name and in her writings described plants in simple layman terms.

Prior to undertaking her world travels, North used watercolours in her earliest illustrations, but once she started to use oils she never returned to watercolours. She wrote that she considered using oils as a 'vice like dram-drinking, almost impossible to leave off once it gets possession of one' (quoted in Moon 1980; Payne 2016). At the time it was unusual for women flower painters to paint in oils (Ryall 2008) and all the paintings exhibited in the Marianne North Gallery are in that medium; her early watercolours are now held in the family collection at Hastings. North appears to have been compulsive about the production of paintings (Brooke 1913), both as a record of her travels, and in her writing, where she used them as descriptive cues for further explanation and context.

The use of oils would have increased the degree of difficulty whilst travelling, as a number of days are required for the surface to dry and transporting wet paintings would have created its own problems. She says nothing in her writings about this challenge or how she dealt with them. Her field technique was described as using the paints 'as they were pressed out of the metal tubes, no turpentine was used for cleaning the brushes, these were merely wiped or squeezed clean with a piece of rag…no attempt is made at over-refinement in any of the works; high finish and minute details would have been impossible under the conditions, and no such details were requisite…the pictures have not even been varnished' (Anon. 1882). North commenced many of her landscape paintings *en plein air* but completed the details upon return to her accommodation. The still life paintings appear to have been completed indoors with the subjects arranged in vases or spread on tables. She mentions in her travels through Western Australia that she used a 'tin biscuit-box half full of damp sand' in which to keep her flower specimens fresh.[8]

North's activities were underpinned by what was termed in the Victorian era as 'nature studies'. These included traditional scientific botany, horticulture, gardening and writing poetry about nature, as well as illustrating plants. These activities were socially acceptable in the strict gender segregation that characterised much of the Victorian era. Botany, because it was associated with a feminine aesthetic tradition became a popular hobby for privileged women, including for leisure-class travellers (Guelke & Morrin 2001). North was an observant and objective documenter, both in her paintings and her writings which overall have a strong theme of botanical and ecological reportage (Standish 2008). Darwin's theories of evolution were at the forefront of scientific initiative at that time, and a significant part of North's approach was to present botanical diversity in an evolutionary context (Carroll 2018); she attempted to demonstrate in her paintings interactions between plants, environment and animals (Kerrigan 2010).

Although North's paintings lack the analytical detail of traditional botanical illustrations, there was enough information for species to be recognised; some were described as new species (Anon. 1914; Goyder et al. 2012;

---

[2] *Recollections*, vol. 1, p. 321.
[3] *Recollections*, vol. 1, p. v.
[4] *Recollections*, vol. 1, p. 33, p. 184.
[5] *Recollections*, vol. 1, p. 34, p. 190.
[6] *Recollections*, vol. 1, p. 34.
[7] *Recollections*, vol. 1, p. 29.
[8] *Recollections*, vol. 2, p. 152.

Watts 2017).[9] For her Australian paintings one new name, *Areca northiana* Hill. ex Hemsl., was provided for a palm she depicted in the Brisbane Botanic Gardens (Hemsley 1882; Dowe 2016a, 2016b, 2018). However, publication of the name was nomenclaturally invalid as no description was provided. The palm resembles a juvenile *Dictyosperma album* (Bory) H.Wendl. & Drude ex Scheff., a species reported as growing in the Brisbane Botanic Gardens at that time (as *Areca rubra* hort. ex H.Wendl.) (Hill 1875). The other new taxa named for North include *Crinum northianum* Baker [= *Crinum asiaticum* L.] (Baker 1882) and *Nepenthes northiana* Hook.f. (Hooker 1881), both of which were illustrated when she was in Borneo in 1880–81;[10] *Kniphofia northiae* Baker [= *Tritoma northiae* (Baker) Skeels] (Baker 1889, 1895) was illustrated in South Africa 1882–83; and the genus *Northia* Hook.f. [= *Manilkara* Adans.] (Hooker 1884), with the type species *Northia seychellarum* Hook.f. illustrated when she was in the Seychelles in 1883–84. Despite suggestions by some authors that she had collected herbarium specimens for Kew, there are only a small number presently located there.[11] However, there is evidence that she frequently acquired living plants and seeds that she returned to Britain and of which some were successful in cultivation (Baker 1891). There is no evidence that she collected seeds or live specimens of any Australian plants for that purpose.

A significant aspect of her botanical paintings for her was to record a 'natural world' that was then deemed to be irreversibly disappearing, primarily through colonial expansion, and industrial and agricultural development. Joseph Hooker contributed the preface to the first edition of the Marianne North Gallery catalogue and wrote that North's paintings were of 'the wonders of the vegetable kingdom; and that these although now accessible to travellers and familiar to readers of travels, are already disappearing or are doomed shortly to disappear before the axe and the forest fires, the plough and the flock, or the ever advancing settler or colonist. Such scenes can never be renewed by nature, nor when once effaced can they be pictured to the mind's eye, except by means of such records as this lady has presented to us, and to posterity' (Hemsley 1882). North frequently commented in her writing on the impact of colonial expansion on the natural forests and vegetation (Ritchie 1989). For example, when in Illawarra in New South Wales, she wrote that she rode 'through miles of tall dead trees all ringed or burnt to death purposely by civilised man, who will repent some day when the country is all dried up, and grass refuses to grow any more'.[12] She visited the theme of environmental impact throughout her writing about Australia, and in the process established herself, somewhat by default, as a witness to, and documenter of rapid environmental change, and in some instances impending degradation. Although North deplored the negative environmental impacts that she witnessed, she accepted it as the price to be paid for 'civilisation' and the advancement of society (Agnew 2011).

From a geographical perspective, previous research has examined North's itineraries and activities in India (Ponsonby 2002; Agnew 2011), Brazil (Siqueira 2015), South Africa (Plug 2014), and Australia and New Zealand (Vellacott1986). Humphrys (2017) provided a brief account of her visit to the Bunya Mountains in Queensland, Davis (2017) discussed aspects of her visit to Illawarra, in New South Wales, and Dowe (2018) investigated North's paintings of Australian botanic gardens. A summary of her botanical activities in Australia was provided by George (2009).

Methods

The present research reconstructs North's travels in Australia from botanical and ecological perspectives with identification of the species she illustrated and relevant observations of landscape and environmental issues as recorded in her published accounts. Primary sources of information examined with regards to her time in Australia include her autobiographical account of her travels and botanising as presented in volume 2 of her book *Recollections of a Happy Life*, which was first published in 1892, two years after her death (the work consulted here was the 2nd Edition, reprinted in 1893 with minor typographical corrections, the addition of a small number of dates, and a few additional footnotes); the paintings themselves from the Marianne North Gallery and from the Royal Botanic Gardens Kew Library, Art and Archives; and the *Official Guide to the North Gallery* (1914, 6th edition), in which the paintings are captioned and provided with numbers; and information contained in some of her surviving correspondence written in Australia to persons in Britain.

Field work was undertaken in retracing North's travel routes in Queensland, New South Wales, Victoria and Tasmania; the locations of her paintings were identified and present-day comparison photographs were taken. Species names and other additions by the author are included in square brackets. The nomenclature of plants and animals follows the Australian Plant Name Index (APNI 2019), the Australian Plant Census (APC 2019), and the Atlas of Living Australia (ALA 2019). Dimensions of the paintings were provided by the Royal Botanic Gardens Kew Library, Art and Archives. North's paintings figured here are reproduced with the permission of the Director and the Board of Trustees, Royal Botanic Gardens, Kew. The paintings not figured here but otherwise referred to in the text by their catalogue number can be viewed at the web sites provided in the footnotes or at https://www.kew.org/mng/gallery/australasia.html.

The Australian paintings

North had a visionary plan to illustrate the distinctive local floras of the world, and Australia held a unique attraction. The purpose of her work was to educate the public, and with her wealth and social connections, she was able to put her plan into action. North was an energetic, determined and business-like traveller who saw her avocation of painting as 'work'. Her travel in Australia was able to be planned as communication and transport systems were mostly in place by the 1880s. Because of her privileged social position and wealth, she was readily accommodated within the structure of the various colonial governments, being hosted by governors, premiers, scientists, prominent citizens and wealthy land owners, and with transport, shelter, food and servants made freely available (Losano 1997; Watts 2017).

---

[9] *Recollections*, vol. 1, p. 251; *Recollections*, vol. 2, pp. 305, 336.

[10] *Recollections*, vol. 2, p. 100.

[11] Personal communication, William Baker and Tim Utteridge, Royal Botanic Gardens Kew.

[12] *Recollections*, vol. 2, p. 137.

North, at the age of 49, undertook the trip to Australia on the suggestion of Charles Darwin; she quoted him saying that she should not attempt any representation of the world flora in her Gallery until she 'had seen and painted the Australian, which was so unlike that of any other country' (Hopper & Lambers 2009).[13] Leaving England with the appropriate letters of introduction, she was able to utilise all the support to be given by the colonial governments and citizens of influence. Of additional interest to resolving North's Australian travels, the newspapers of the time provided an almost running commentary on her activities and movements as she was considered a person of public interest and a minor celebrity. A prelude to her visit was published in Australian newspapers as early as July 1880, a month prior to her arrival. The following extract provides an insight into the expectation of the privileges that North was to receive in Australia:

> The object of the visit is thus described in the accompanying letter of Sir Joseph D. Hooker:- "A very accomplished artist, Miss Marianne North, is about to visit these Colonies of Australia, New Zealand, South Africa, and the Mauritius, mainly for the purpose of making, at her own cost, accurate paintings of the remarkable trees and plants of these countries, for presentation to the Royal Gardens at Kew. These paintings will complete a series, which already includes several hundreds of views of a similar character by Miss North, in Brazil, the West and East Indies, Japan, North America, and Canary Islands, which she has presented to the Royal Gardens, together with a munificent sum of money for building a gallery for exhibiting the whole series to the public, and which gallery is now being erected." Sir J.D. Hooker adds:- "I need not observe upon the importance of such aid in relation to the fern trees of Australia, the pines, etc. of New Zealand, and innumerable other trees and plants of these and other colonies; and when it is considered that this lady's paintings will be National property, and be copied for important works devoted to commercial, educational, and industrial objects, it is not too much to say that the absence of such an aid would be matter of natural regret;" and he concludes, "should the Right Honourable the Secretary of State for the Colonies consider it expedient to transmit a copy of this letter to the Government of the several Colonies about to be visited by Miss North (she seeks no private introductions), such action would, I feel sure, be most gratifying to that lady, and to the wide circle interested in her labours, and be of great future advantage to the public, both Home and Colonial." The Secretary of State does so consider, and expresses his confidence that our Government will gladly afford to Miss North every facility and aid in carrying out her project.[14]

North presented herself as a representative of British botanical enterprise, albeit a non-intrusive traveller and a non-collecting collector in contrast to the rapacious activities of many Victorian plant hunters who were then active in Australia and other places of the world (Raby 1996). During the 207 days spent in Australia (1 August 1880, arrival date at Thursday Island, Queensland, to 18 February 1881, departure date from Hobart, Tasmania), she completed at least 80 paintings. Much of her time was taken up by travel by ship, horse, coach and rail, and socialising with colonial government officials, including governors and premiers, or persons associated with them. She also met and interacted with scientists, horticulturists and artists. This suggests that she had a very rapid output and completion rate, considering the limited time available to paint and the conditions under which she sometimes had to work.

An early estimate of the number of Australian plant species that she depicted was about 120 but this did not seek to name all the plants illustrated 'as specific names have only been given to such as could be identified with ease, or without too great an expenditure of time' (Hemsley 1886). This current research has identified about 200 species of plants and about 20 species of animals depicted in North's Australian paintings (Appendix 1). In a summary of the extent of the botanical subjects in the gallery collection, the Australian paintings were described as 'perhaps, the finest of the collection, very fully illustrating the most striking features of the marvellous Australasian flora' (Anon. 1914).

All the Australian paintings were originally executed on paper, and only later, a few years after her death, were mounted on a stout backing board for support and preservation. The paper, a medium-weight cotton rag, was prepared with a white ground and sized to prevent oil absorption and was considered to be serviceable, portable and inexpensive (Millard et al. 2011). In 2008, the entire collection of paintings in the Marianne North Gallery was the subject of an interventive conservation program managed by Kew Gardens. At the same time, the gallery building was completely renovated to allow for improved preservation conditions for the paintings into the future (Millard et al. 2011). During the conservation program, every painting was unframed, cleaned and removed from the original mounts. After the making of high resolution photographs (front and reverse), they were remounted and reframed using archival standard materials. Many of North's original inscriptions on the reverse sides of her paintings were revealed for the first time. For the Australian paintings these have provided additional notes and comments not otherwise recorded, and have added to a better understanding of her *modus operandi*, both in the field and whilst preparing the paintings for hanging in the Gallery.

---

[13] *Recollections*, vol. 2, p. 87.

[14] *The Mercury* (Hobart), 10 July 1880, p. 2, 'The Mercury'.

Queensland

Destined for Australia, North departed Singapore on *R.M.S. Normanby* on 19 July 1880. Sailing to the north of Java and passing 'Cape Jacki' (Jaco Island off the far eastern coast of Timor), they traversed the Arafura Sea and entered Torres Strait.[15] On 1 August, *R.M.S. Normanby* passed Booby Island which is located about 50 km west-north-west of Cape York. Later that day they arrived at Thursday Island, her first landfall in Australia. The following day, 2 August, they departed Thursday Island and sailed south through the Albany Passage. The first botanical observations to be made by North in Australia were from the deck as the steamer passed between Albany Island and the mainland of Cape York Peninsula before entering the open waters of the Coral Sea.[16] She wrote that 'we were so close to each shore that we saw all the trees perfectly: mangroves, casuarinas [*Allocasuarina littoralis* or *Casuarina equisetifolia* var. *equisetifolia*], brown granite rocks and red sand, with giant ants' nests like obelisks of the same colour [termite mounds] … On the other shore [Albany Island] … low hills dotted with dracaena trees [*Pandanus tectorius*].[17]

Upon reaching Brisbane on 8 August (**Fig. 3**),[18] North was at first accommodated in a hotel, but the following day moved to Government House to be the guest of Joshua Peter Bell, Lady Bell and Georgina Kennedy. Bell was the Colonial Administrator in the temporary absence of Governor Sir Arthur Kennedy; Georgina Kennedy was the Governor's daughter. Government House was situated adjacent to the Brisbane Botanic Gardens which were then under the curatorship of Walter Hill.[19] North immediately went to work painting in the gardens and in the next few days completed five paintings (Dowe 2018) [**paintings 732, 738, 743, 783, 790**].[20] One painting, in her established format of a landscape across which was placed a feature plant in the foreground, North painted from the rear window of Government House, looking west, with Mt Coot-tha in the far distance and the Government House parterre in the near distance (**Fig. 4; painting 738**). Kew Director Joseph Hooker, in a letter of introduction to Walter Hill, wrote that North's object was to paint 'characteristic specimens of your palms, cycas, tree ferns, araucarias, &c., of which you may be able to furnish the names. Any aid you can afford to Miss North will be very valuable'.[21] To this end it was reported that 'Miss North was working hard all day on Monday at the native palms in the Brisbane Botanic Gardens, and which she expressed herself highly pleased'.[22]

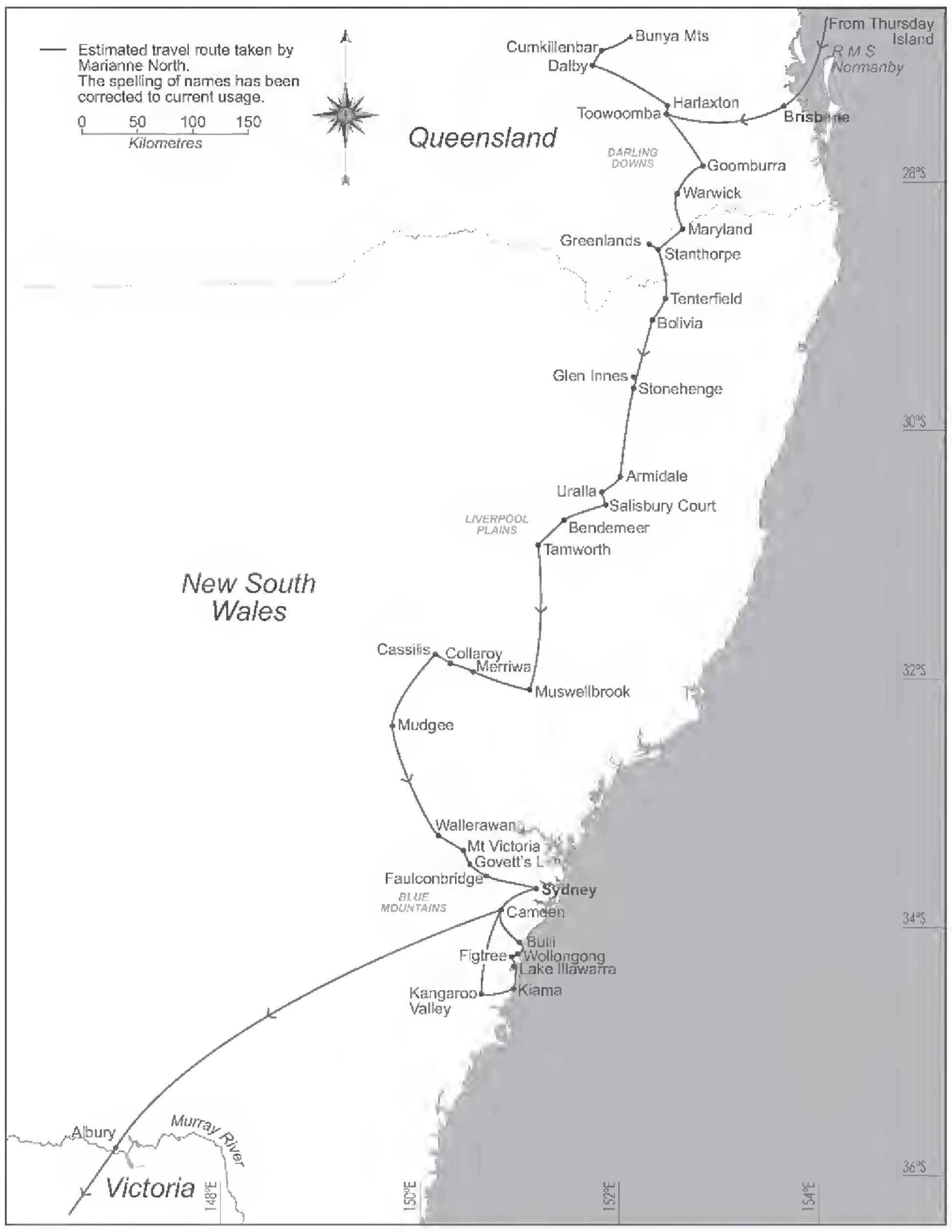


Fig. 3. Map showing the travel route of Marianne North through Queensland and New South Wales, 1880. Prepared by Claire Burton.

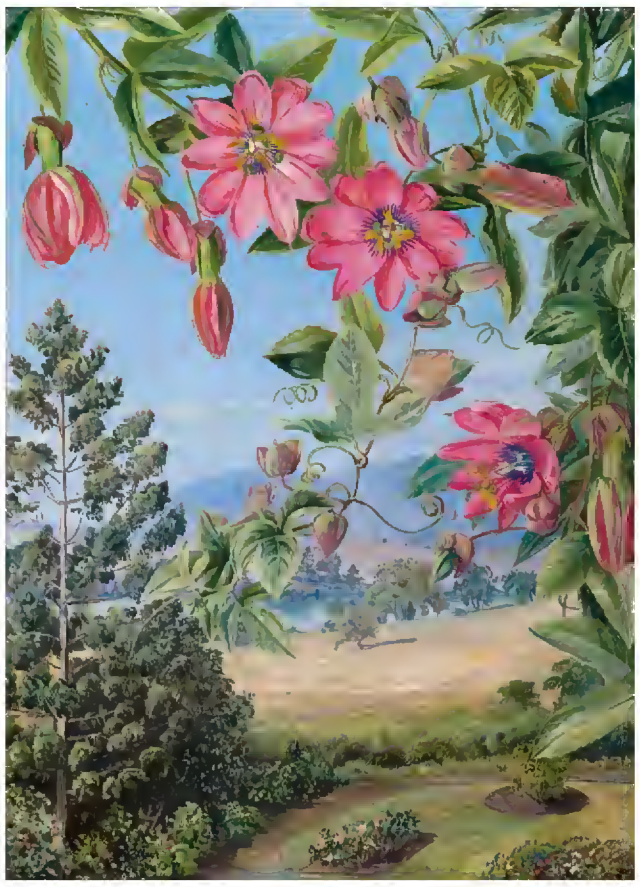


Fig. 4. *738. View in the Brisbane Botanic Gardens*. Oil on board, 47.1 x 33.8 cm. *Passiflora* sp. [North's Tacsonia] (vine); *Araucaria cunninghamii* Aiton ex A.Cunn. (left middle ground). © Royal Botanic Gardens, Kew.

Illustrating the adaptation of birds to a specific manner of fruit manipulation and feeding, North depicted a black cockatoo feeding on the fruit of *Macadamia integrifolia* (**Fig. 5; painting 790**). In an observation of the great diversity of parrots in Australia, North wrote: 'No one can have an idea of parrots without going to Australia … one great black one with yellow ears and tail [*Calyptorhynchus (Zanda) funereus*] I painted eating the Queensland nut, whose shell is so hard that (like that of the Java kanari tree [*Canarium indicum*]) he alone can crack it with his huge beak'.[23]

---

[15] *Brisbane Courier*, 4 Aug. 1880, p. 2, 'Arrival of the Torres Straits Mail at Cooktown.'

[16] *Darling Downs Gazette and General Advertiser*, 4 Aug. 1880, p. 3, 'Arrival of the Torres Straits Mail at Cooktown'.

[17] *Recollections*, vol. 2, p. 106.

[18] *Brisbane Courier*, 9 Aug. 1880, p. 2, 'Shipping'.

[19] *Queenslander*, 14 Aug. 1880, p. 197, 'Current news'.

[20] www.kew.org/mng/gallery/732.html; www.kew.org/mng/gallery/743.html; www.kew.org/mng/gallery/783.html.

[21] *Queenslander*, 14 Aug. 1880, p. 197, 'Current news'.

[22] *Brisbane Courier*, 10 Aug. 1880, p. 3. [Editorial]

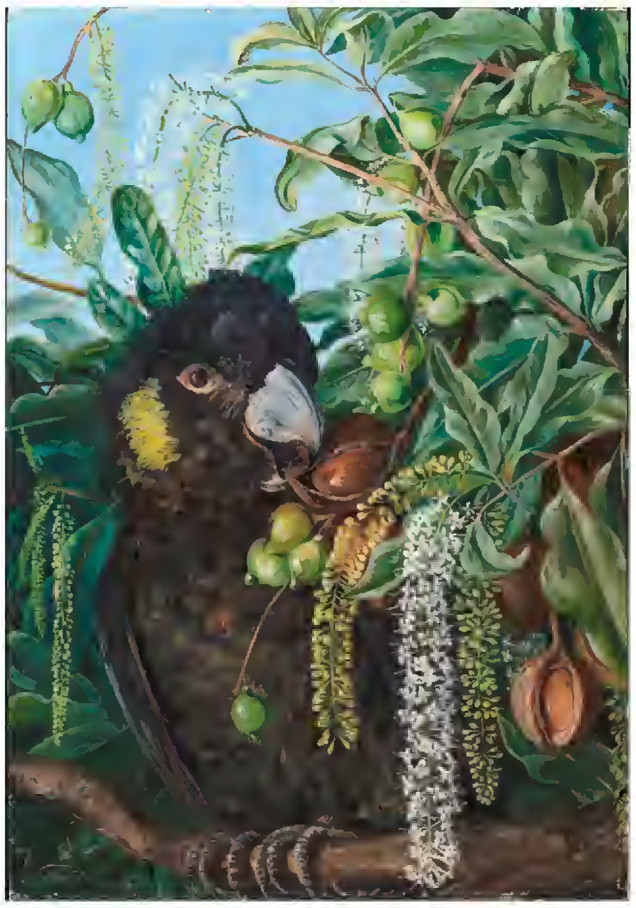


Fig. 5. *790. Foliage, Flowers, and Fruit of a Queensland Tree, and Black Cockatoo.* Oil on board, 50.9 x 35.4 cm. *Macadamia integrifolia* Maiden & Betche [North's Queensland nut]; *Calyptorhynchus (Zanda) funereus* (Shaw, 1794) (Yellow-tailed black cockatoo). © Royal Botanic Gardens, Kew.

On 14 August, North departed Brisbane for Toowoomba by train, continued on to Dalby and finally to Cumkillenbar Station where she was the guest of pastoralist Samuel Moffat, his wife Maria Susanna Moffatt and their family of five daughters [**painting MNS47**].[24] Her plan was to visit the nearby Bunya Mountains to explore the most westerly rainforest in southern Queensland and paint the forests of *Araucaria bidwillii*. Between Brisbane and Toowoomba she wrote that she travelled 'through forests of gum-trees, with the yellow wattles or acacias [*Acacia* spp.] just coming into bloom, and a few grass-trees [*Xanthorrhoea* sp.] here and there, whose trunks and wiry grass-like heads were blackened by the fires which natives make inside them in order to get a grand blaze at once, but which never really kill them. These trees are called "black boys" all over Australia…Stag's-horn ferns [*Platycerium superbum*] grow on the stumps'.[25]

North completed her first painting of an Australian landscape on 17 August on the track from Cumkillenbar Station to the Bunya Mountains **[painting 737]**.[26] At Bunya Mountains she described *Araucaria bidwillii* with trunks 'perfectly round, with purple rings all the way up, showing where the branches had been once, straight as arrows up to the leafy tops, which were round like the top of an egg or dome, and often 200 feet above the ground. Only the ends of the branches had bunches of leaves on them, and only a third of the stem had branches left on it. But these grand green domes covered one hundred miles of hill-tops, and towered over all the other trees of those forests' **[Fig. 6, painting 767]**.[27] She described the understory as being 'roped together by fantastically twisted lianes, and great creeping roots, like the snake-tree of Jamaica, dracaenas, ferns, and the sandal-wood raspberry'.[28] The bird life was also depicted, and North wrote that she 'found many of the trees hung with whip-bird's nests – long hanging pockets of the greenest moss, the entrance often decorated with the feathers of the blue and red parrot' [**painting 771**].[29] She depicted their camp site at Dandabah looking to the north-west across the sedge swamp **[Fig. 7, painting 768]**. Dandabah Swamp contains the only known population of *Phragmites australis* in the Bunya Mountains (Moravek et al. 2013), and which North depicted in her painting of the camp. This location is now a tourist camping ground and interpretation centre for the Bunya Mountains National Park **(Fig. 8)**.

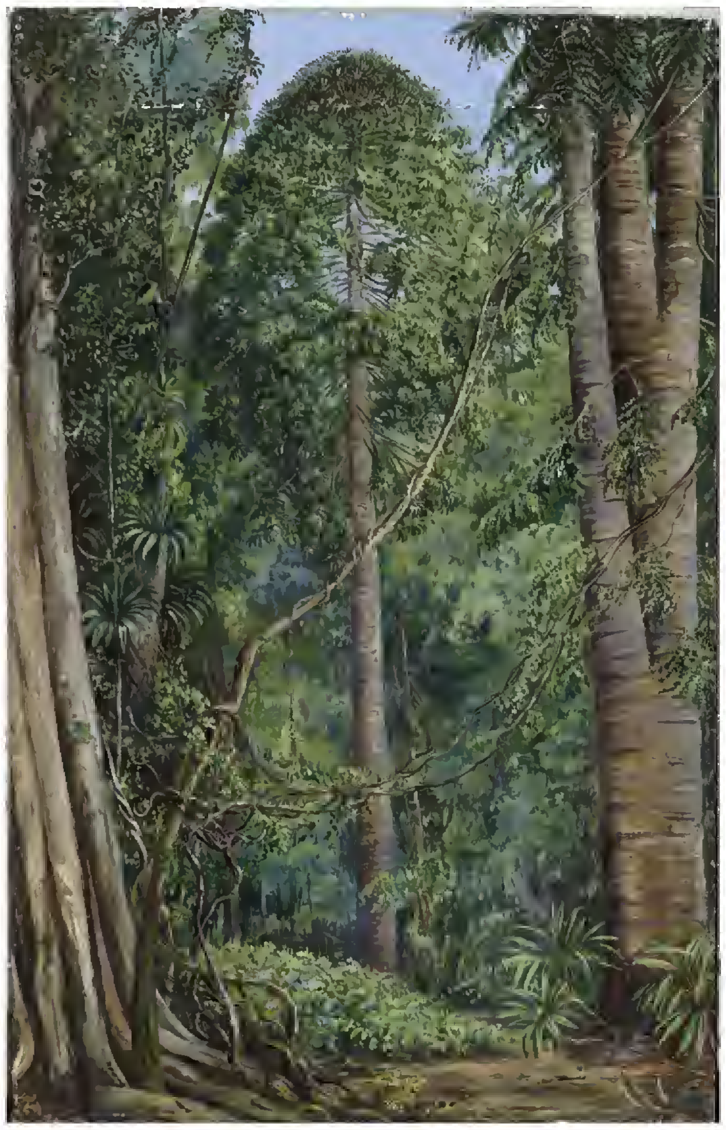


Fig. 6. *767. Study of the Bunya-Bunya.* Oil on board, 55.7 x 35.6 cm. *Araucaria bidwillii* Hook. (distance and right); *Cordyline petiolaris* (Domin) Pedley [North's dracaena] (foreground); *Asplenium australasicum* (J.Sm.) Hook. [North's birds'-nest ferns] (epiphytic on tree to left). © Royal Botanic Gardens, Kew.

---

[23] *Recollections*. vol. 2, p. 110.

[24] Paintings prefixed with MNS are held in the Royal Botanic Gardens Kew Archives, Art and Library.

[25] *Recollections*, vol. 2, p. 111.

[26] *Recollections*, vol. 2, p. 114; www.kew.org/mng/gallery/737.html.

[27] *Recollections*, vol. 2, p. 114.

[28] *Recollections*, vol. 2, p. 115.

[29] www.kew.org/mng/gallery/771.html.

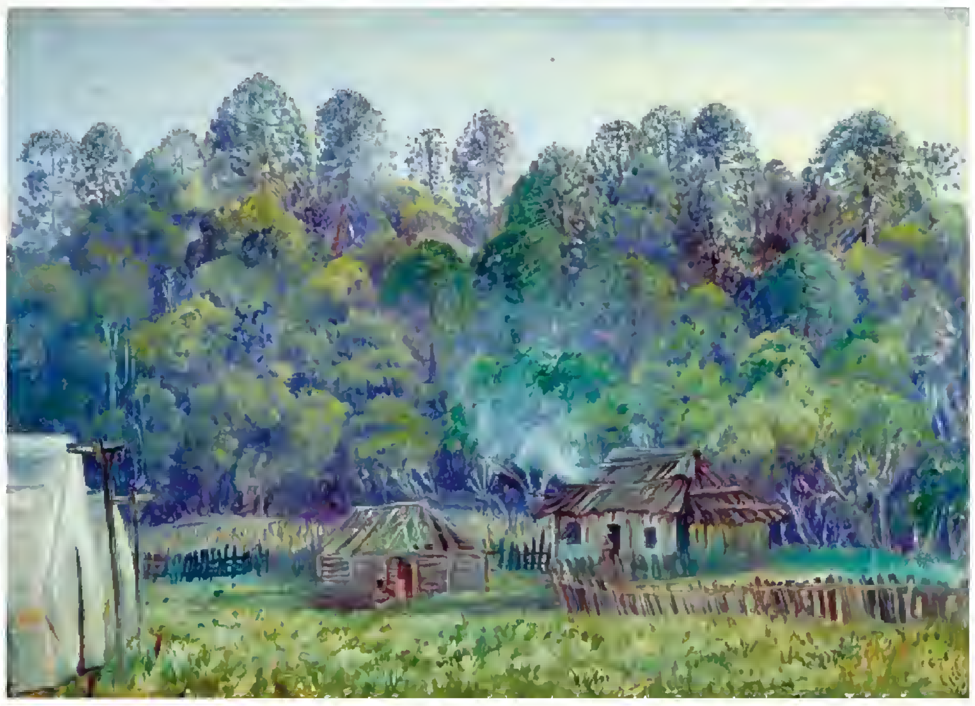


Fig. 7. *768. Our Camp on the Bunya Mountains, Queensland.* Oil on board, 25.4 x 35.7 cm. *Araucaria bidwillii* Hook. (distance); *Acacia* sp. (middle distance); *Poa labillardieri* Steud. (grass, foreground); *Phragmites australis* (Cav.) Trin. ex Steud. (sedge, middle ground). © Royal Botanic Gardens, Kew.

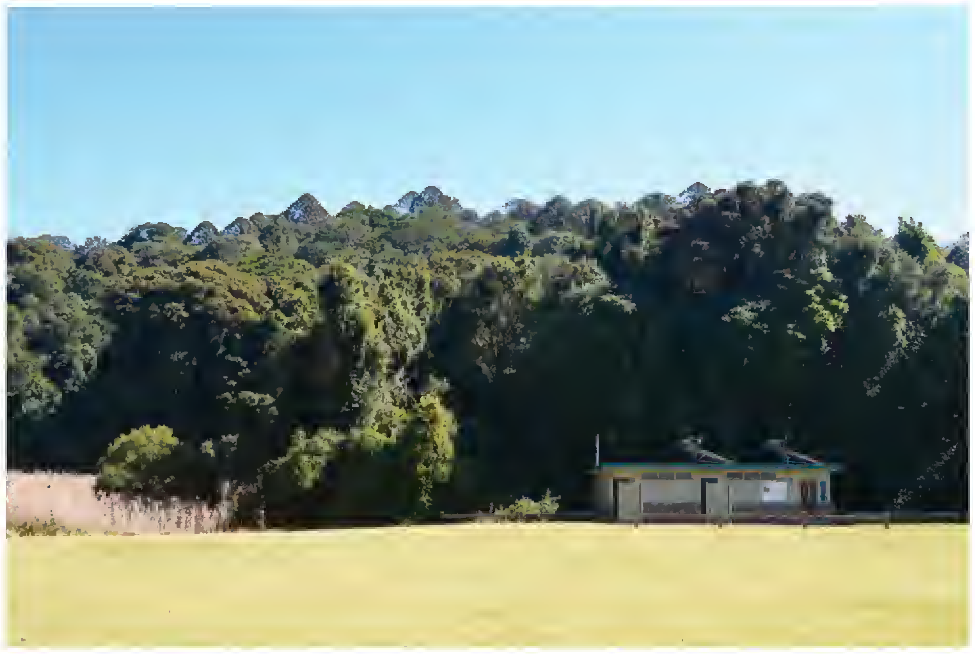


Fig. 8. View of Dandabah Swamp (June 2017), with the same view as depicted in Marianne North's painting no. *768*. Photo: J.L.Dowe.

The following day North wrote that 'we climbed up to the top of the highest point, and got a grand view over the yellow burnt-up plains, with now and then patches which looked like lakes, and miles of forest-covered tops. I had my first sight of a party of perhaps twenty kangaroos, all hopping down the hill in single file, or feeding in the hollow below. I can fancy no more comical sight than a procession of these strange creatures, proceeding over the long tufted grass in the way I saw them then, using their big tails for balancing-rods' **[painting 773]**.[30]

On 18 August, North wrote that she 'saw still bigger bunya trees, and great skeleton fig-trees [*Ficus watkinsiana*] hugging some other victim-tree to death, with its roots spreading over the ground at its base like the tentacles of some horrid sea-monster **[Fig. 9, painting 781]**. We rested an hour at a partial clearing over a wood-shoot, from whence there was a far distant view over the distant Bunya Mountains and the plain below, with scraggy old casuarinas [*Casuarina* sp. or *Allocasuarina* sp.] and a gigantic fig-tree [*Ficus* sp.] as foreground, with tree-ferns [*Cyathea australis* or *Cyathea cooperi*] and seaforthia palms [*Archontophoenix cunninghamiana*] (the most elegant of the whole family). Birds'-nest ferns [*Asplenium australasicum*] were clinging to the trees, and a kind of dracaena [*Cordyline petiolaris*] - with slender bending stem leaned against them for support. On the ground were violets with grass-like leaves [possibly *Hybanthus enneaspermus* or *Murdannia graminea*], and a few yellow everlastings [Asteraceae sp.] but no other flowers. Great piles of saw-dust and chips, with some huge logs, told that the work of destruction had begun, and civilised man would soon drive out not only the aborigines but their food and shelter' **[painting 763]**.[31] This painting is a view from Carbines Chute (North's 'wood-shoot') looking east to Mt. Garrow, one of the grassy 'balds' that are a feature of the Bunya Mountains (Moravek et al. 2013). North's use of the term wood-shoot would have been unfamiliar to English readers: North often included examples of Australian language and vernacular in her writing.

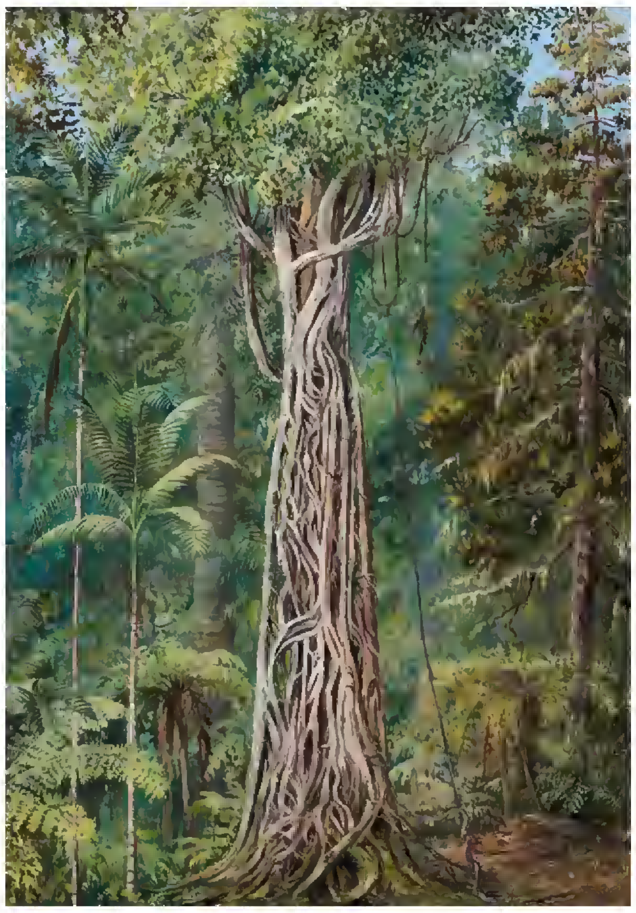


Fig. 9. *781. Poison Tree strangled by a Fig, Queensland.* Oil on board, 50.8 x 35.4 cm. *Archontophoenix cunninghamiana* (H.Wendl.) H.Wendl. & Drude [North's seaforthia palms] (left); *Dendrocnide moroides* (Wedd.) Chew (host of strangler fig); *Ficus watkinsiana* F.M.Bailey [North's skeleton fig tree] (strangler fig); *Araucaria bidwillii* Hook. (right); *Cyathea* sp. (right foreground); *Alectura lathami* (J.E.Gray, 1831) (Brush turkey). © Royal Botanic Gardens, Kew.

A summary of North's delight and interest in all she saw at the Bunya Mountains was expressed in a letter she wrote to Amelia Edwards: 'Gov & Mrs Bell were most kind & he at once arranged to send me to the Bunya mountains to see the Great Auraocarias - his cousins the Moffats sent up tents & took me with 4 of their children for four days there - it was very cold but I saw such wonders I forgot the climate - such gorgeous parrots little wooly native bears, kangaroos &

---

[30] *Recollections*, vol. 2, p. 115; www.kew.org/mng/gallery/773/html.

[31] *Recollections*, vol. 2, pp. 115–116; www.kew.org/mng/gallery/763.html.

wallabies & two dozen hopping over the long burnt up grass - I defy anyone to look at their proceedings without laughing - everything was strange & new'.[32]

North and the Moffats departed the Bunya Mountains on 19 August, returning to Cumkillenbar Station passing through forests with scattered *Brachychiton rupestris*. North wrote that 'these curious trees are really like bottles, with a crown of willow-like leaves; the ends of the branches being tipped with ivy-shaped leaves, and the very youngest plants having their lower stems shaped like a radish. They are always found at the edge of the forest, and never more than one or two in a group' **[Fig. 10, painting 736]**.[33] In her painting, North depicted a rapidly moving grass fire thus offering an insight into the fire-ecology associated with open forests in that area. She provided further insight as to how fire was perceived comparatively by both the European settlers and the Indigenous people. She wrote that 'fire came alarmingly near the tents; but the trees are so full of moisture that they never catch fire till after many days of scorching, while the grass blazes up and is out at once … when by accident the flames come too near, every white man, woman, and child has to take branches and beat it out, while the blacks sit down and sigh. The young grass is stifled by the dense mass of dry tufts above it. The only way of giving it necessary room and air is by burning off the old grass, and its ashes are the best manure for the young shoots'.[34] North did not explain whether this fire was accidental or deliberately lit, but on other occasions she wrote that some fires were started by the carelessness of the settlers.

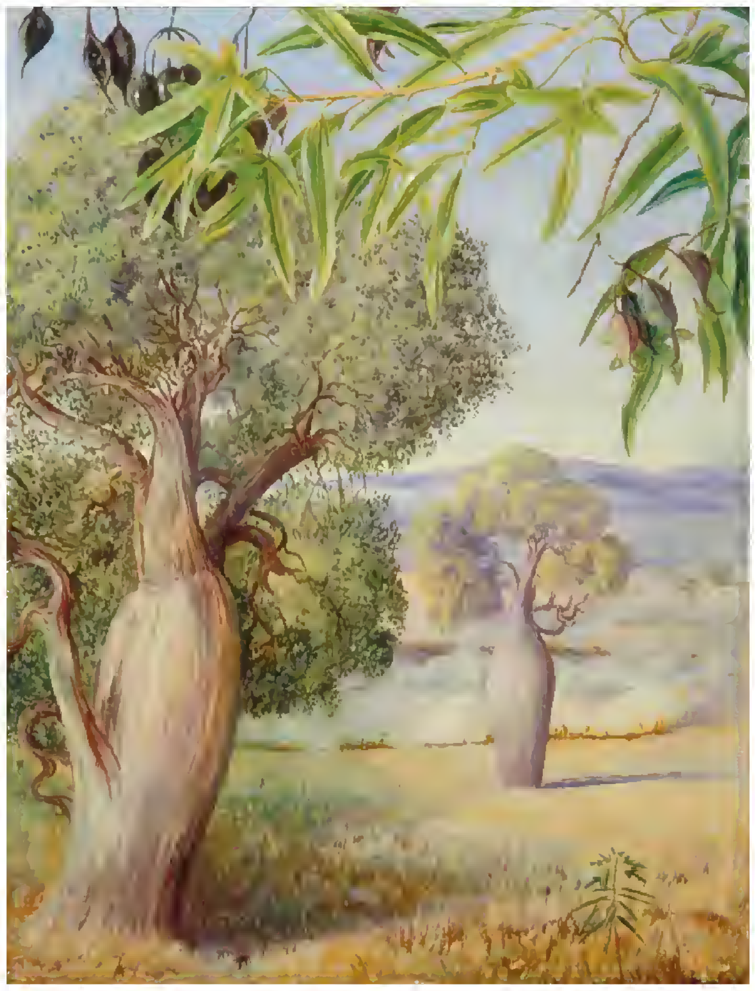


Fig. 10. *736. The Bottle Tree of Queensland.* Oil on board, 44.8 x 34.3 cm. *Brachychiton rupestris* (T.Mitch. ex Lindl.) K.Schum. [North's bottle-tree]. © Royal Botanic Gardens, Kew.

On about 24 August, North departed Dalby and travelled by train to Harlaxton (north of Toowoomba), where she was the guest of the former explorer and then Commissioner of Crown Lands, Francis Thomas [Frank] Gregory (1821–1888). She wrote of 'a glorious view over "the Range," as the hills are called between it and Brisbane. They are covered with unbroken forest, having a peculiar deep bloom on them seen only on masses of the gum-trees. At sunset the view was particularly lovely, when the gray branches and white stems of the near trees were tinted with rose-colour like the sky itself" **[Fig. 11, painting 745]**.[35] North's painting is of the view from the veranda of Harlaxton (which survives as a heritage listed building), looking north-east (**Fig. 12**).

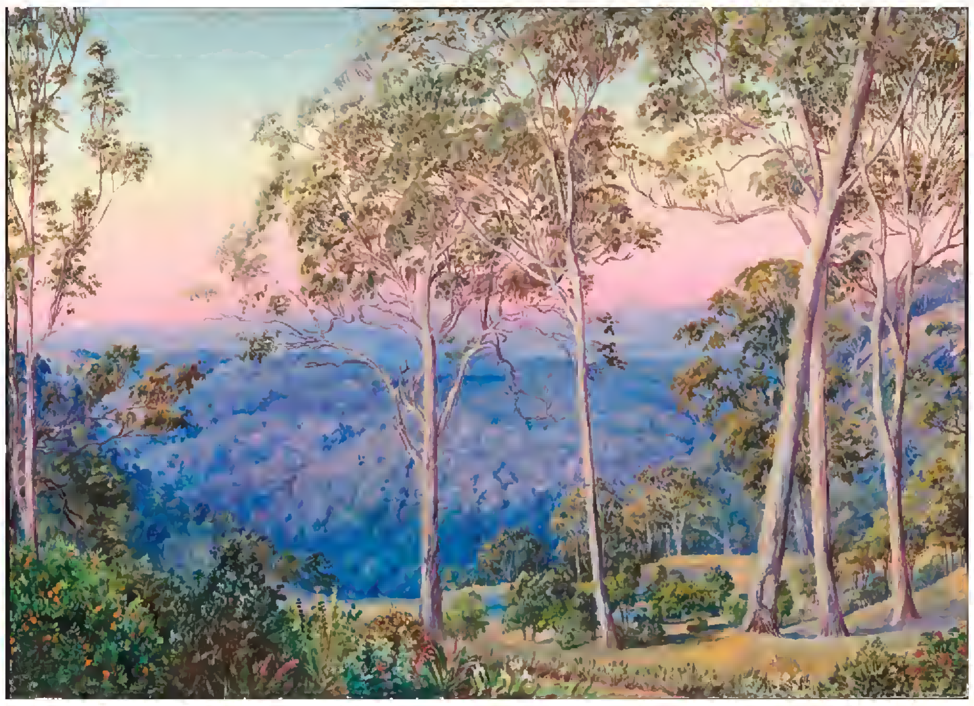


Fig. 11. *745. Evening Glow Over "The Range".* Oil on board, 34.4 x 47.7 cm. *Eucalyptus* spp. © Royal Botanic Gardens, Kew.

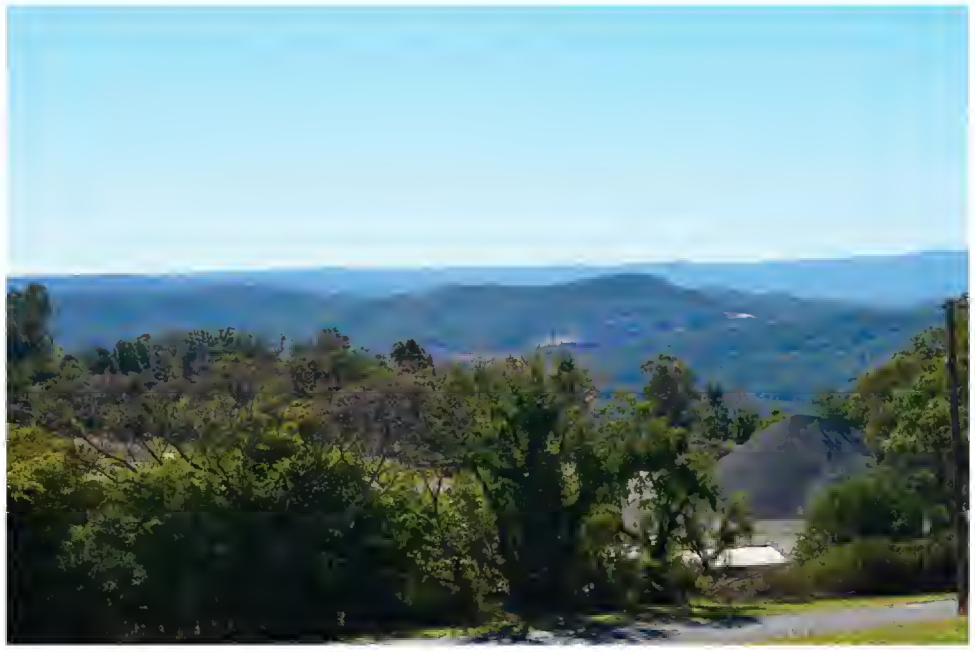


Fig. 12. View from Harlaxton (June 2017), showing the same view as depicted in Marianne North's painting no. *745*. Photo: J.L.Dowe.

On 29 August, North travelled by train from Harlaxton to Goomburra (North's Gumbara) where she was hosted by pastoralist Edward Weinholt. Here was North's first experience of a large bush fire where she wrote that 'the hills were on fire, and the foreground was black with a fire that was only just over. All that was unburnt was browned by frost and want of moisture. Stunted white stemmed trees were dotted about, and not a flower was to be found' **[Fig. 13,**

---

[32] M. North to A. Edwards, 15 Sept. 1880. ABE 254, Somerville College Library, Oxford University.

[33] *Recollections*, vol. 2, p. 118.

[34] *Recollections*, vol. 2, p. 117.

[35] *Recollections*, vol. 2, p. 120.

painting 787].[36] North's painting is of the view looking east from Goomburra homestead (**Fig. 14**). The highest feature depicted is locally known as Holmes Pinnacle.[37]

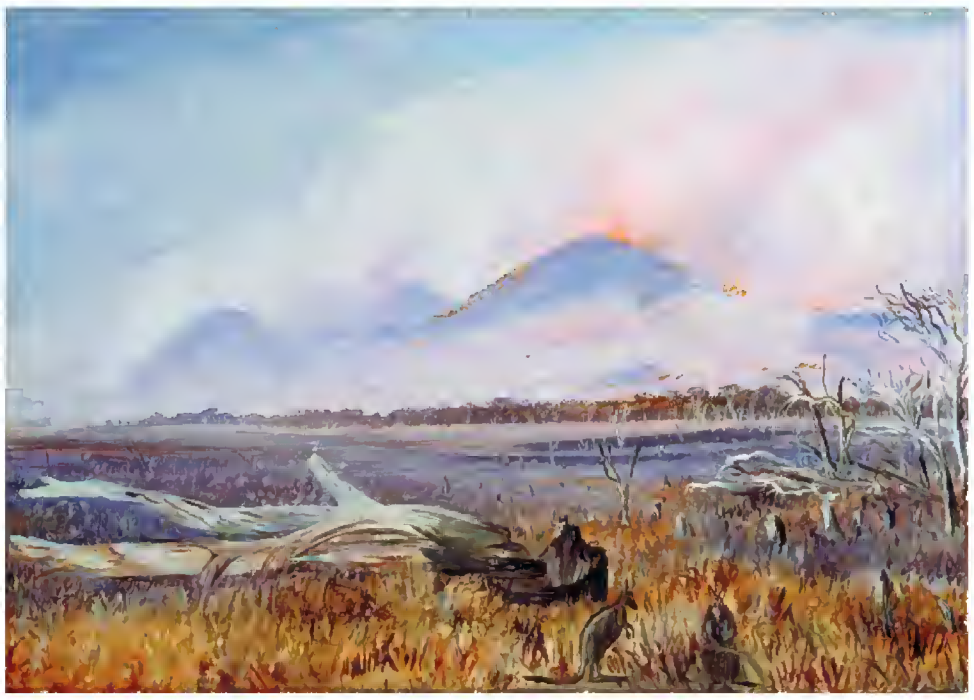


Fig. 13. *787. A Bush Fire at Sunset, Queensland.* Oil on board, 25.5 x 35.5 cm. *Macropus* sp. (Wallaby). © Royal Botanic Gardens, Kew.

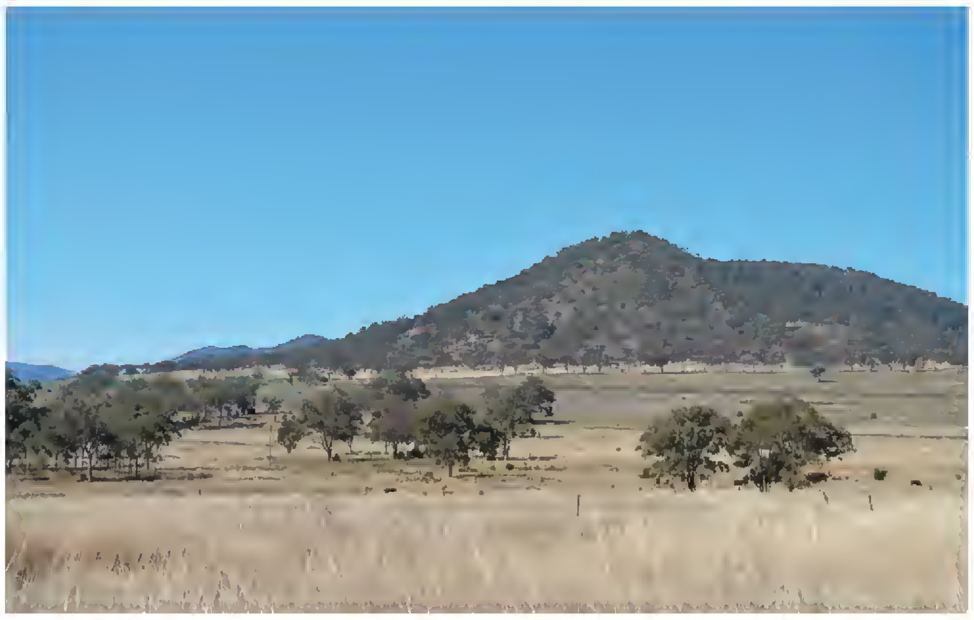


Fig. 14. View from Goomburra (June 2017), showing the same view as depicted by Marianne North in painting *787*. Photo J.L. Dowe.

On 2 September, North crossed the border from Queensland into New South Wales to visit Maryland station then managed by Alfred Greenup. At Maryland, she described the Kurrajong (*Brachychiton populneus* subsp. *populneus*) with 'a rough reddish bark, with bright-green ivy shaped leaves, which made it very conspicuous among the gray gum leaves, with their smooth marble-like trunks. The apple-trees [*Angophora floribunda*] were another exception to the gray leaves, though less bright than the currajong. Their trunks and branches were twisted into the most fantastic shapes, and in their knobbiest corners water could always be found by tapping' **[painting 779]**.[38] North later returned to Stanthorpe. Here she visited nearby Greenlands Station **[painting 726]**,[39] before travelling south to leave Queensland.

New South Wales

On about 5 September, North boarded a Cobb & Co. coach at Stanthorpe travelling southward to Tenterfield and towns beyond (**Fig. 3**). During this period, North had little time for painting as the coach made few stops. They passed through Glen Innes, Stonehenge, Bolivia and Armidale until she reached Uralla where she stayed at Salisbury Court as the guest of Mrs. Marsh, widow of Charles Marsh and sister-in-law of Matthew Marsh, absentee owner of Maryland. North's transit through the area was reported in the local newspapers and stated that 'Miss North, a lady known to fame as a sketcher, passed through Glen Innes a few days since'.[40]

North Travelled through the northern tablelands of New South Wales when the region was in drought.[41] In New South Wales, between Tenterfield and Armidale, she wrote: 'The dryness was sad to see. We constantly passed poor dying and dead beasts by the roadside, which were left to be devoured by wild dogs and cats, and afterwards had their bones cleaned by the ants'.[42]

On 14 September she reached Bendemeer (as Bendemere), where she observed a 'pretty green meadow with a clear river running through it, bordered by casuarina trees [*Casuarina cunninghamiana* subsp. *cunninghamiana*] or "she-oaks," so called from the original native name of shiock, which had been again varied into "he-oaks," "swamp oaks," and even "oaks" alone, all being species of casuarina, a tree as unlike the English oak as it is possible to find. They looked golden in the setting sun, a pretty picture, with the gray native companion-birds [*Grus rubicunda*] stalking in and out of the water' **[painting 728]**.[43] North's use of the term she-oak for species of *Casuarina* is an example of the persistent adoption of common names for Australian plants given by early explorers and colonists. The origin of the various Australian 'oaks' appears connected to the appearance of the pattern in the wood that resembled the English oaks, however the origin of the specific appellation she-oak remains obscure.

From Tamworth on 15 September, North took a train to Muswellbrook [as Musselbrook], and then a coach to Merriwa, and on to Collaroy on 18 September where she was the guest of stud owner Charles Clive. She observed that 'on the top of a steep hill, from whence he had a view over the rich cleared country dotted with gumtrees, and winding river, bordered with so-called "oaks," to the Liverpool range' **[Fig. 15, painting 770; painting 769]**.[44] North also painted a possum that was found 'in an old stump', and was pulled 'out by its prehensile tail for me to paint' **[painting 748]**.[45]

---

[36] *Recollections*, vol. 2, pp 120–121.

[37] Personal communication, Mary Mannings, Warwick and District Historical Society.

[38] *Recollections*, vol. 2, p. 122; www.kew.org/mng/gallery/779.html.

[39] www.kew.org/mng/gallery/726.html.

[40] *Armidale Express and New England General Advertiser*, 14 Sept. 1880, p. 6, 'District News.'

[41] (https://www.abs.gov.au/AUSSTATS/abs@.nsf/lookup/1301.0Feature%20Article151988),

[42] *Recollections*, vol. 2, p. 127.

[43] *Recollections*, vol. 2, p. 128; www.kew.org/mng/gallery/728.html.

[44] *Recollections*, vol. 2, p. 130; www.kew.org/mng/gallery/769.html.

[45] *Recollections*, vol. 2, p. 130; www.kew.org/mng/gallery/748.html.

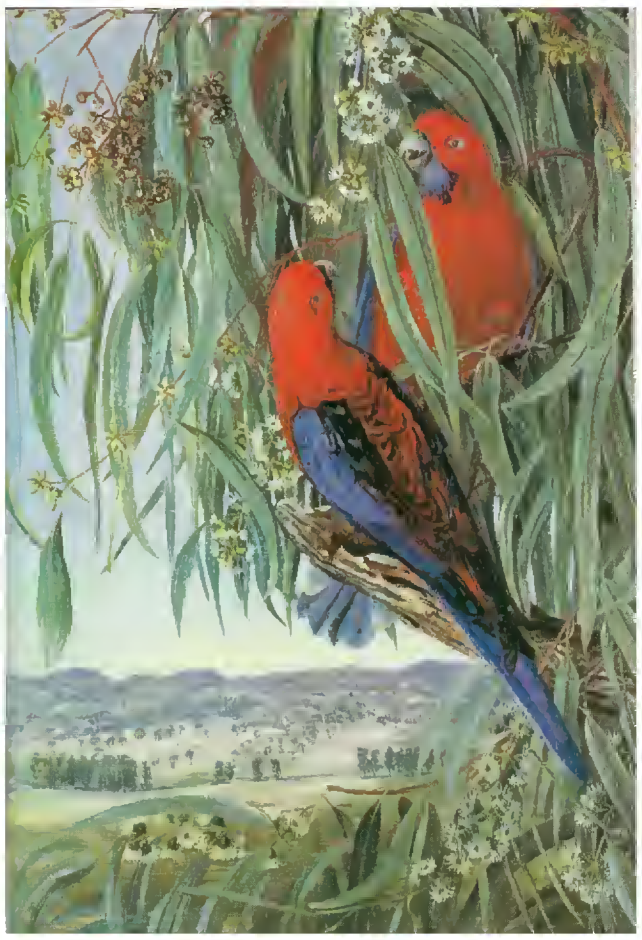


Fig. 15. *770. View from Collaroy, New South Wales, Looking Towards the Liverpool Downs.* Oil on board, 50.8 x 35.5 cm. *Eucalyptus nicholii* Maiden & Blakely (foreground); *Casuarina cunninghamiana* Miq. subsp. *cunninghamiana* [North's oaks] (distance); *Platycercus (Platycercus) elegans* (Gmelin, 1788) (Crimson rosella). © Royal Botanic Gardens, Kew.

From Collaroy, a buggy was taken to Cassilis on 21 September, and then onto Mudgee where she was the guest of Nelson Lawson, grandson of explorer William Lawson, and his wife [**painting 792**].[46] On 22 September, North took a train from Mudgee via Wallerawang to Mt Victoria. Here she observed 'forests of many wonders, the gum-trees having a darker foliage than any I had seen before, the young shoots of a bronze or copper tint loaded with berries of a purple bronze, the younger shoots very blue. Under the tall trees were all manner of flowers; but the waratah [*Telopea speciosissima*], just opening, quite took my breath away with its gorgeousness. It is like a large peony in size and colour, with its petals formed like English honeysuckles, the buds like gray shells. Each head stands on a separate stalk of four or five feet high, with splendid thistle-like leaves' **[painting 785]**.[47]

North arrived in Sydney later that day and was given a tour of the Sydney Botanic Gardens by naturalist George Bennett. She wrote that 'the gardens were lovely, but I longed for the country, and escaped to Camden, thirty miles off, by rail and road—one of the oldest settlements of New South Wales, and certainly the most lovely garden in Australia'.[48] North rested at Camden for a few days as guest of William Macarthur and his niece Bessie Macarthur, before travelling to Illawarra [**painting 603**].[49] The Macarthurs provided her with a buggy and driver to travel to Illawarra for one week commencing on 4 October. In Illawarra, North was the guest of the Osborne family, wealthy owners of many properties in the district (Griffith 2015). Upon reaching the lowlands, North travelled through the villages and settlements toward Lake Illawarra. She described the descent to Bulli: 'I went through pretty scenery till I reached the top of the llewarra Mountains, and went down the wonderful bit of road to Bulli. At the top I saw many specimens of the great Australian lily or doryanthes [*Doryanthes excelsa*] [**paintings 778, 884**],[50] but they were not in flower. … There was a fine sea-view, and lower down the road took me through the richest vegetation, quite unlike anything else south of Brisbane. Tall seaforthia palms [*Archontophoenix cunninghamiana*] and cabbage or fan palms [*Livistona australis*], full of flower, many of them of great height. Often one had helped itself up in the world by means of the branches of a giant gum-tree, resting its tired head against the trunk for support, quite 200 feet above the ground in the valley below' **[Fig. 16, painting 760]**.[51]

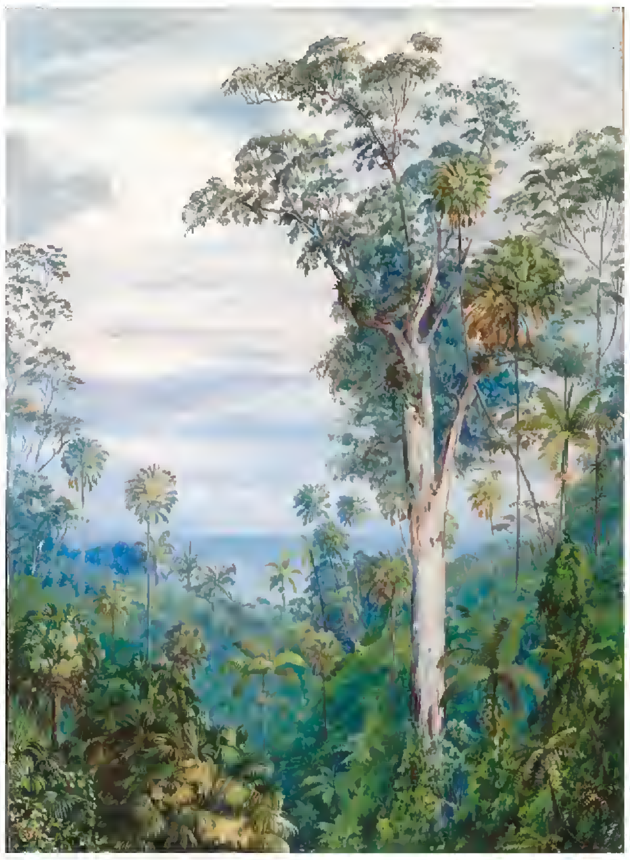


Fig. 16. *760. White Gum Trees and Palms, Illawarra, New South Wales.* Oil on board, 47 x 34.1 cm. *Eucalyptus pilularis* Sm. (distance); *Eucalyptus botryoides* Sm. (foreground); *Livistona australis* (R.Br.) Mart. [North's cabbage or fan palm] (distance and foreground); *Archontophoenix cunninghaniana* (H.Wendl.) H.Wendl. & Drude [North's seaforthia palm] (distance and foreground) *Pandorea pandorana* (Andrews) Steenis (vine, white flowers, left foreground). © Royal Botanic Gardens, Kew.

On 7 October, North passed through the village of Figtree, and wrote that she 'stopped to paint a gigantic fig-tree [*Ficus macrophylla*] standing alone, its huge buttresses covered with tangled creepers and parasites. The village was called Fig-tree village after it, and all the population was on horseback, going to the races at Wollongong' **[painting 788]**.[52] The Annual Wollongong Races were held over two days on 7–8 October in 1880.[53] The fig tree illustrated by North was a well-known feature at that time (Gardiner-Garden 1953),[54] and survived until 1996 when it was removed because of disease.[55]

---

[46] www.kew.org/mng/gallery/792.html.

[47] *Recollections*, vol. 2, p. 133; www.kew.org/mng/gallery/785.html.

[48] *Recollections*, vol. 2, pp 134–135.

[49] www.kew.org/mng/gallery/603.html.

[50] www.kew.org/mng/gallery/778.html. This painting, 778, of *Doryanthes excelsa* was one of three paintings of Australian plants that were completed after her return from Australia and based on plants in cultivation in England. The other paintings were of *Doryanthes excelsa*, 884, www.kew.org/mng/gallery/844.html, and *Swainsona formosa*, 718, www.kew.org/mng/gallery/718.html.

[51] *Recollections*, vol. 2, p. 135.

On 8 October, North arrived at Doondale, one of the Osbornes' properties. She wrote that the garden 'was a sight to see: pink and white *Azalea indica* fit for London shows, *Bougainvillea* with three yellow blooms at once in their purple bracts, flame-trees (*Sterculia*) [*Brachychiton acerifolius*], gorgeous Cape lilies, and all our home-flowers in perfection… It had a valley of ferns a mile off and one could see miles of cabbage-palms [*Livistona australis*] below like gigantic Turk's-head brooms, such as housemaids use to sweep away spiders with' **[Fig. 17, painting 727]**.[56] The extensive land clearing in this area caught North's attention (**Fig. 18**), and she wrote that 'the road along the coast to Kiama (pronounced "Kye-aye-mar") was dreary enough, through miles of tall dead trees all ringed or burnt to death purposely by civilised man, who will repent some day when the country is all dried up, and grass refuses to grow any more' **[painting 716]**.[57] The clearing of forests in Illawarra occurred very rapidly and extensively from the 1820s through to the 1880s (Bywater 1980; Fallding & Benson 1985).

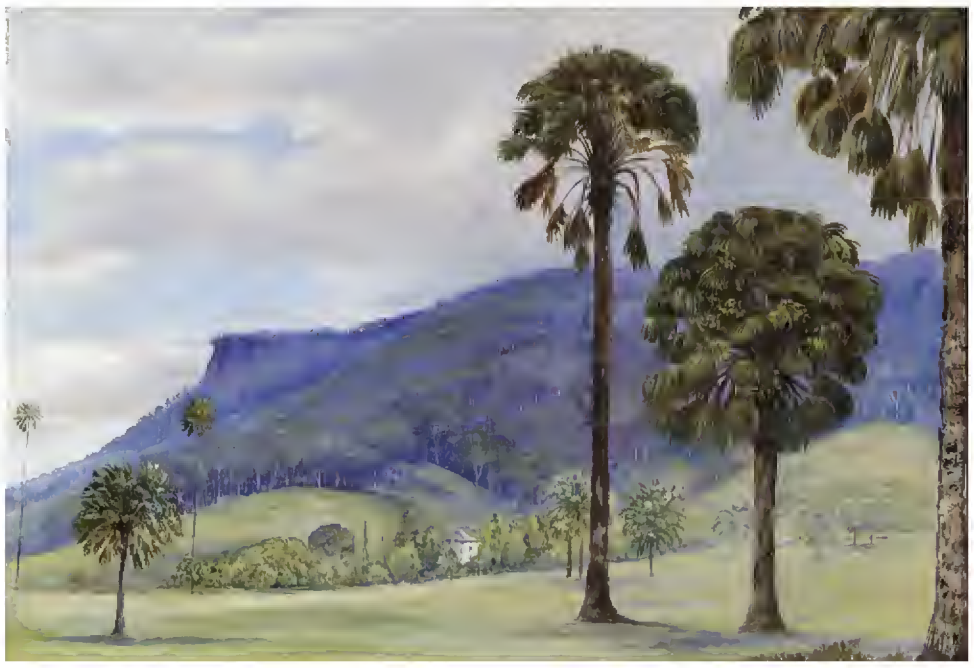


Fig. 17. *727. View at Illawarra, New South Wales.* Oil on board, 25.4 x 35.4 cm. This painting is a view looking south to Broker's Nose. *Livistona australis* (R.Br.) Mart. © Royal Botanic Gardens, Kew.

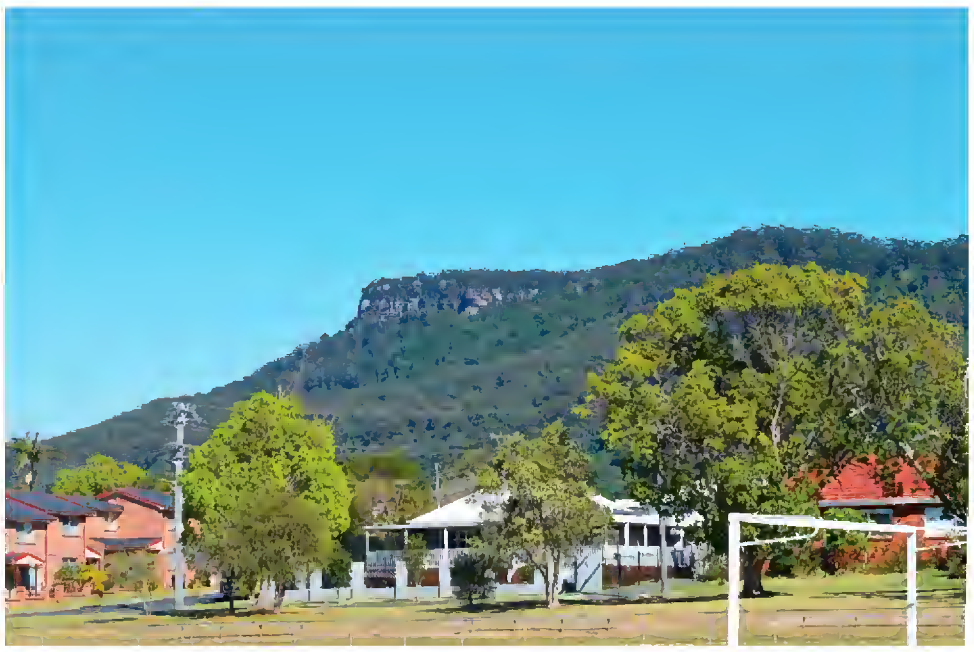


Fig. 18. View of Brokers Nose (September 2017), showing the same view as depicted by Marianne North in painting no. *727*. Photo: J.L.Dowe.

On 11 October, North departed Illawarra to return to Camden via Kangaroo Valley, where she observed 'the zamia or cycad [*Macrozamia communis*] — a most striking plant, with great cones standing straight up from the stem. When ripe the segments turn bright scarlet, and the whole cone falls to pieces, then they split open, and show seeds as large as acorns, from which a kind of arrowroot can be extracted, after washing out all the poison from it. The natives roast and eat the nut in the centre of the scarlet segments. There were no zamias outside that valley, which seemed to have no outlet' **[painting 719]**.[58]

After a short stay at Camden and a visit to Sydney where she met the natural history illustrator Helena Forde (Olsen 2013), she travelled to Faulconbridge in the Blue Mountains to stay with Clarinda Parkes, the wife of Henry Parkes, and her daughter Lily Maria Parkes. Henry Parkes, who was then Premier of New South Wales, was away on business at that time. Faulconbridge House, which still stands, is in Sir Henry's Parade located opposite the main entry to Jackson Park.[59] At Faulconbridge, she wrote that she found 'twenty-five different species of wildflowers in ten minutes, close to the house, and painted them … it was far too cold for out-of-doors sketching or dawdling, and I worked on steadily in my room' **[Fig. 19, painting 759]**.[60] This painting was one of many in which North depicted mass arrangements of locally collected flowers, with the painting being completed indoors so that the flowers could be appropriately arranged and kept fresh.

---

[52] *Recollections*, vol. 2, p. 136; www.kew.org/mng/gallery/788.html.

[53] *Australian Town and Country Journal*, 16 Oct. 1880, p. 33, 'Wollongong Annual Races.'

[54] *Illustrated Sydney News*, 16 Oct. 1867, p. 3, 'The big fig tree.'

[55] Personal communication, Leon Fuller; Wollongong City Libraries. Figtree, Parish of Wollongong, County of Camden. www.wollongong.nsw.gov.au/library/onlineresources/suburbprofiles/Pages/Figtree.aspx, accessed 31 Aug. 2017.

[56] *Recollections*, vol. 2, pp 136–137.

[57] *Recollections*, vol. 2, p. 137; www.kew.org/mng/gallery/716.html.

[58] *Recollections*, vol. 2, p. 137; www.kew.org/mng/gallery/719.html.

[59] Personal communication, Richard Morony.

[60] *Recollections*, vol. 2, p. 138.

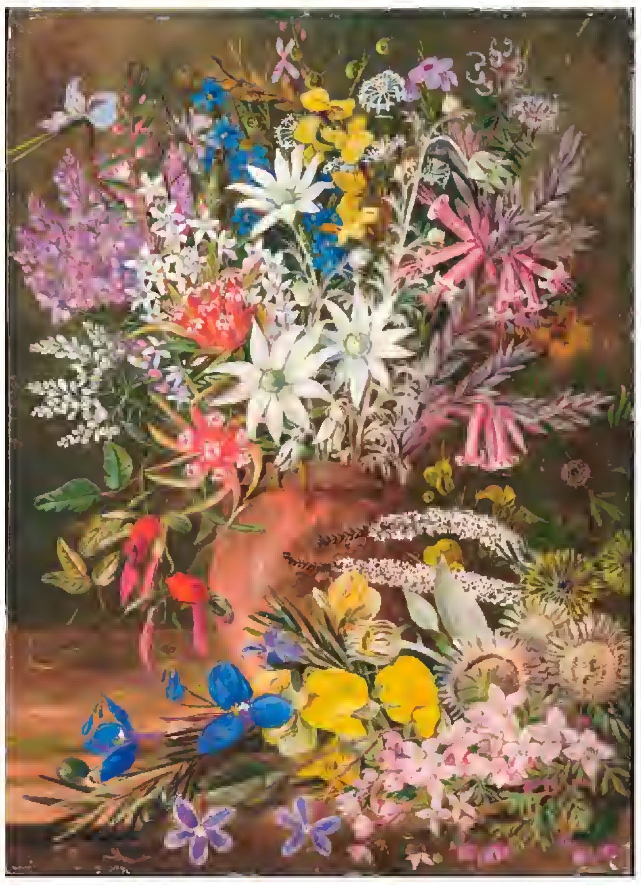


Fig. 19. *759. Wild Flowers of the Blue Mountains, New South Wales.* Oil on board, 47.3 x 34.2 cm. Clock-wise from top left: *Diuris punctata* Sm. (mauve orchid); *Philotheca myoporoides* (DC.) Bayly (white flowers); *Dampiera stricta* (Sm.) R.Br. (blue flowers); *Stylidium graminifolium* Sw. (mauve flowers); *Gompholobium grandiflorum* Sm. (yellow flowers); *Pimelea linifolia* Sm. (white flowers); *Tetratheca ciliata* Lindl. (pink flowers); *Grevillea buxifolia* (Sm.) R.Br. (white flowers); *Styphelia tubiflora* Sm. (pink flowers); *Daviesia ulicifolia* Andrews (orange flowers); *Epacris longiflora* Cav. (pink flowers); *Woollsia pungens* (Cav.) F.Muell. (white flowers); *Isogogon anemonifolius* (Salisb.) Knight (yellow flowers); *Helichrysum* sp. (cream flowers); *Boronia floribunda* Sieber ex Rchb. (pink flowers); *Bauera rubioides* Andrews (pink flowers); *Pultenaea canescens* A.Cunn. (yellow flowers); *Philotheca salsolifolia* (Sm.) Druce (mauve flowers); *Patersonia glabrata* R.Br. (blue flowers); *Kennedia rubicunda* (Schneev.) Vent. (red flowers); *Lambertia formosa* Sm. (red flowers); *Comesperma ericinum* DC. (mauve flowers); *Actinotus helianthi* Labill. (white flowers). © Royal Botanic Gardens, Kew.

Two more paintings were completed at Faulconbridge, and North wrote that 'the native pear [*Xylomelum pyriforme*] was in both fruit and flower [**painting 739**].[61] I painted it, and also a pretty little kangaroo-rat which Lily had had as a pet' **[painting 710]**.[62] North's paintings depict a view looking north-east toward Mt Tomah.

On 19 October, North returned to Sydney where she was the guest of the natural historian William John Macleay and his wife Susan Emmeline at Elizabeth Bay House. William was the cousin of the pastoralist and explorer Sir George Macleay. Of Elizabeth Bay House and Sydney Harbour she wrote that 'the garden was lovely, the bay as blue as an Italian lake, with headlands crossing one another at the end, and three islands covered with woods and small houses' [**Fig. 20, painting 749**].[63] North's painting of a view of Sydney Harbour from Elizabeth Bay House was from a window of what is now known as the morning room on the upper floor (**Fig. 21**). The present-day veranda was not added to the house until 1892 and the morning room now has the veranda in front of the windows.[64] Although North noted that there were three islands to be seen from Elizabeth Bay House, there are indeed only two, these being Clarke Island, in the near-distance and Shark Island, in the far-distance. Her third 'island' may have been one of the headlands protruding into Sydney Harbour visible from Elizabeth Bay.

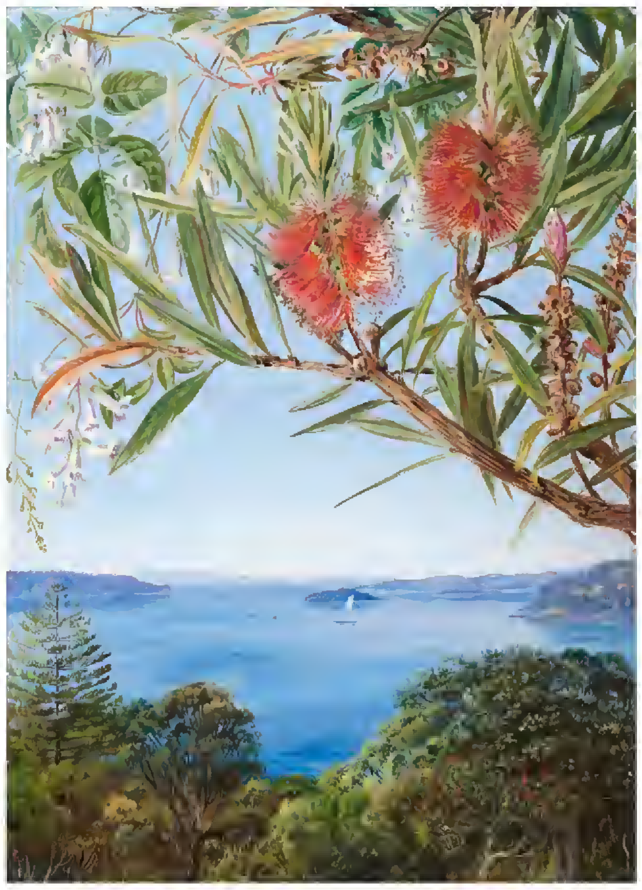


Fig. 20. *749. Two Australian Shrubs, with Sydney Harbour Below*. Oil on board, 47.2 x 43.1 cm. *Pandorea pandorana* (Andrews) Steenis (vine, white flower, left foreground); *Callistemon citrinus* (Curtis) Skeels (centre and right foreground); *Ficus* sp.(right foreground); *Leptospermum* sp. (middle foreground); *Araucaria heterophylla* (Salisb.) Franco (left foreground). © Royal Botanic Gardens, Kew.

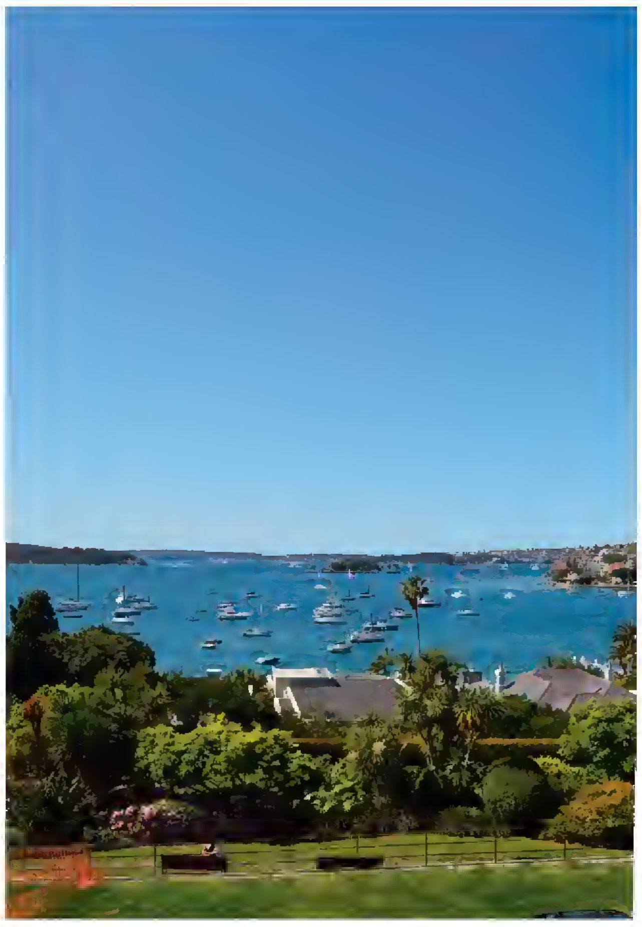


Fig. 21. Sydney Harbour from the 'morning room' window at Elizabeth Bay House (September 2017), with the same view as depicted by Marianne North in painting no. *749*. Photo: J.L.Dowe.

---

[61] www.kew.org/mng/gallery/739.html.

[62] *Recollections*, vol. 2, p. 139; www.kew.org/mng/gallery/710.html.

[63] *Recollections*, vol. 2, p. 139.

[64] Personal communications, Melissa Flyte, Elizabeth Bay House.

Victoria

On about 23 October North departed Camden by rail and then took a coach to Albury and then on to Melbourne (**Fig. 22**).[65] North did not record the town where the train to coach transfer occurred. She did not complete any paintings during this time of travel, but upon arrival in Melbourne was able to resume painting. She wrote that ‘as we got nearer Melbourne we saw miles of pasture, covered with a kind of coloured dandelion (*Cryptostemma calendulacea*) [*Arctotheca calendula*], whose seed was brought over from the Cape only a few years before and now grew everywhere; but it did no harm, for the cattle ate it’ **[Fig. 23, painting 742]**.[66]

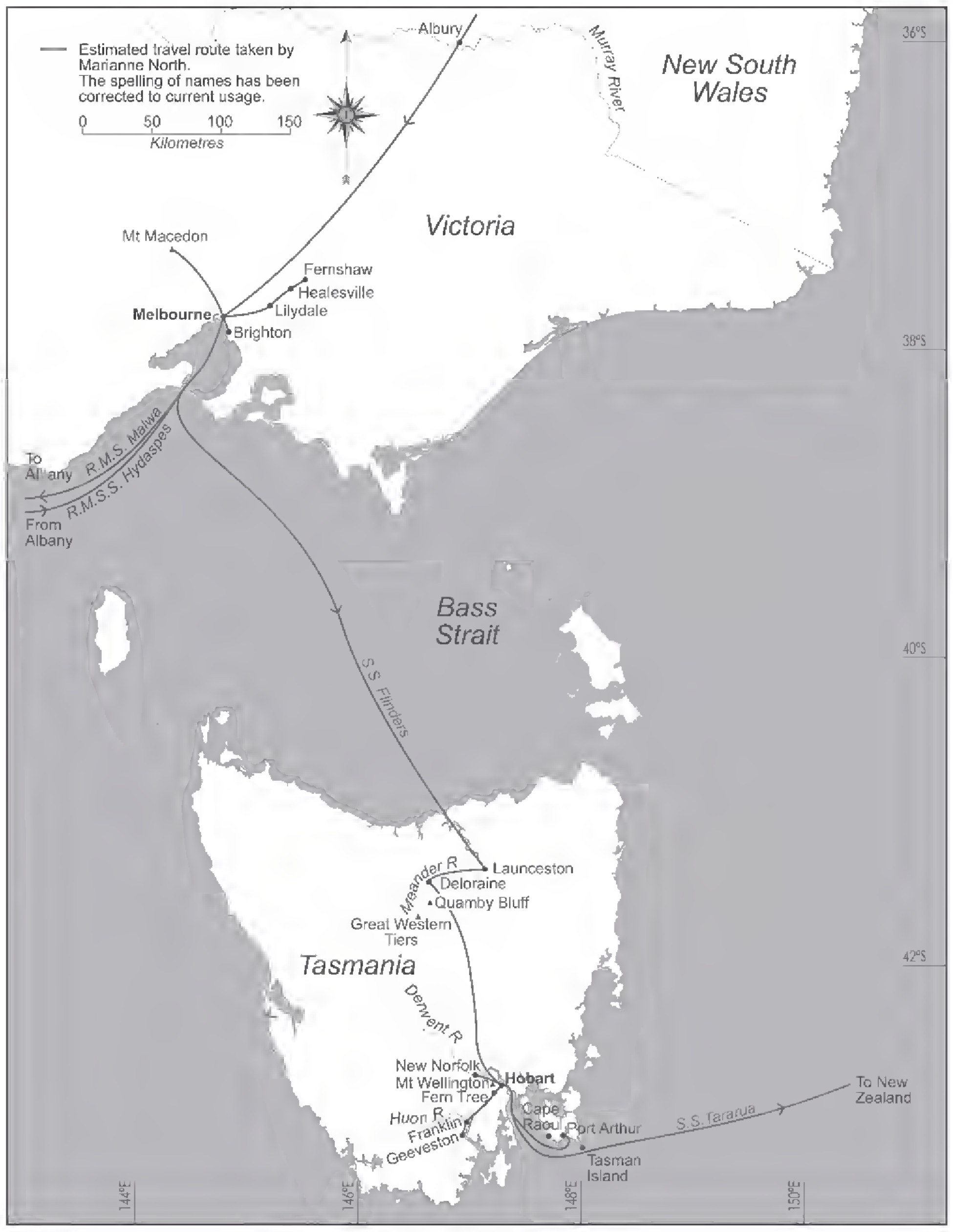


Fig. 22. Travel route taken by Marianne North through Victoria and Tasmania, 1880–1881. Prepared by Claire Burton.

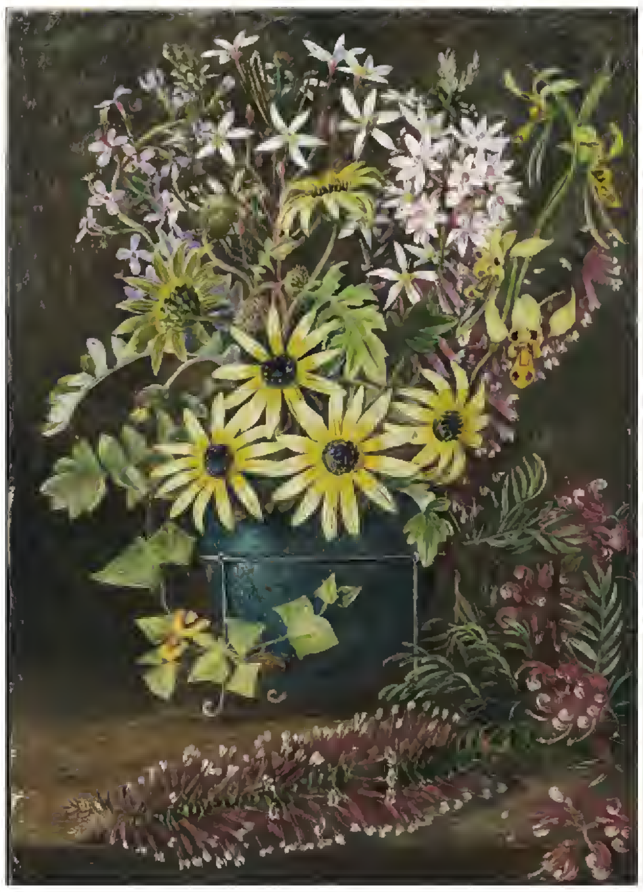


Fig. 23. *742. Wild Flowers of Victoria and New South Wales.* Oil on board, 35.7 x 25.5 cm. Clock-wise from top left: *Stylidium* sp. (pink flowers): *Campanulaceae* sp. (white flowers); *Platysace* sp. (white/pink flowers); *Diuris* sp. (donkey orchid, yellow flowers); *Epacris longiflora* Cav. (pink/white flowers, behind donkey orchid); *Grevillea* sp. (red flowers); *Epacris longiflora* Cav. (pink/white flowers, foreground); *Platylobium triangulare* R.Br. (vine, yellow flowers); *Arctotheca calendula* (L.) Levyns (North’s *Cryptostemma calendulacea*) (daisy, yellow flowers). © Royal Botanic Gardens, Kew.

In Melbourne, from about 26 October, North was the guest of William Campbell and his wife at their city residence on the corner of Collins and Spring streets. Campbell was a wealthy pastoralist, gold entrepreneur and financier, and represented the seat of North-Western Province in the Victorian Legislative Council 1862–82. Although North met with the botanist Baron Ferdinand von Mueller a number of times, it is not known who showed her around the Melbourne Botanic Gardens, as Mueller had vowed never to set foot there following his controversial dismissal as director in 1873 (Vellacott 1986; Maroske 2014). North painted a view of the Melbourne Botanic Gardens from the Eastern Lawn looking toward the Royal Exhibition Building in the far distance, and which, in 1880, had just been completed and opened for the Melbourne International Exhibition (Oct. 1880 - Apr. 1881) (**Fig. 24; painting 754**). At the Campbell’s second house at Brighton, North painted a view of Brighton Beach as seen from near the residence. This view is looking south with Brighton Beach in the lower right, Green Point in centre-ground, Sandringham (now Trey Bit Reserve) in the left middle-distance, and Mornington Peninsular in the very far distance. The location of the Campbell’s house, where Marianne stayed, according to the 1880 edition of the Sands & MacDougall directory was in Leslie Road (now Grove), Brighton, which runs off Were Street and is two blocks from Port Phillip Bay.[67] The Jim Willis Reserve now protects the remaining vegetation between the main road (Beach Road) and the shore line. The beach profile has been altered by the placement of a number of groynes along this stretch of the coastline. North wrote that she saw 'quantities of another less showy variety [*Leptospermum laevigatum*] planted along the edge of the sea to bind the sand the whole shore was lined with it … I had a delightful drive and scramble round the low cliffs and headlands, finding quantities of long spiral sundews [*Drosera auriculata*] and other treasures' [**painting 752**].[68]

---

[65] *Argus*, 25 Oct. 1880, p. 5, ‘Overland passengers to and from Sydney’.

[66] *Recollections*, vol. 2, p. 141.

[67] Personal communication, Sandra Lanteri, Brighton Historical Society.

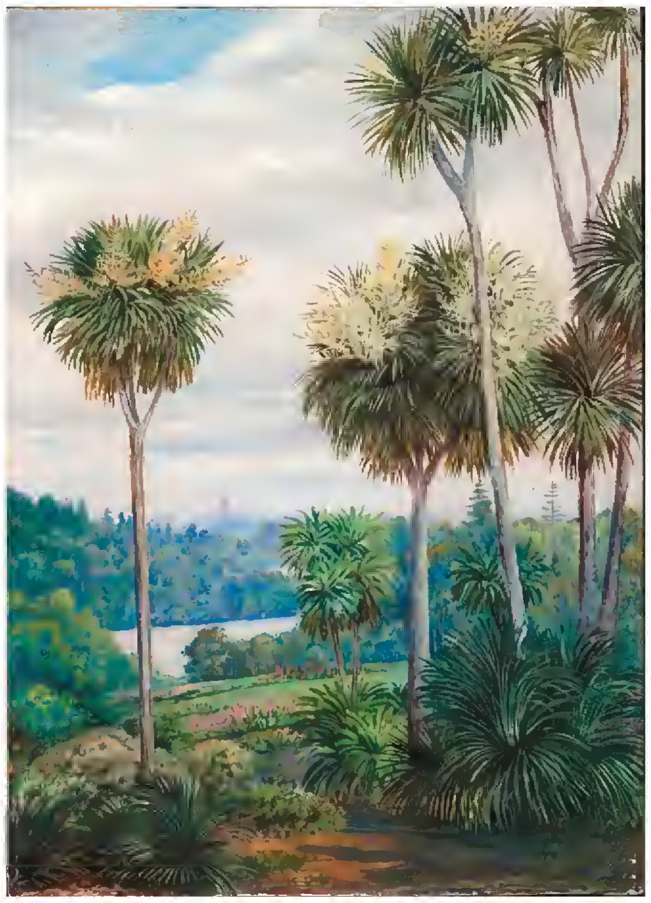


Fig. 24. *754. View of Melbourne, From the Botanic Gardens*. Oil on board, 35.7 x 25.5 cm. Conifer sp. (distance); *Cordyline australis* (G.Forst.) Endl. [North's *dracaena*] (foreground); *Araucaria* spp. (middle distance); *Xanthorrhoea* sp. (grass trees, foreground). © Royal Botanic Gardens, Kew.

On 4 November, North travelled to Fernshaw via Lilydale and Healesville to see the *Eucalyptus regnans* forests. She stayed four days there, and completed seven paintings. The eucalypt forests in this area contain some of Australia's tallest trees. She wrote: 'After leaving Healesville I got on the box-seat, and saw the lovely forest as we mounted the steep ascent. The driver said he did not believe any of the trees were 320 feet, and that they could make the Baron [Ferdinand von Mueller] believe anything they liked; but it was a noble forest. The trees ran up like gigantic hop-poles, with thousands of tree-ferns under them, also straight, and thirty feet high, swelling much at the base of their stems, a nice undergrowth of young gums and other shrubs under them again' **[painting 777]**.[69] She continued: **'**We found our way under the lace-work roof of fern-fronds [*Cyathea australis* or *Dicksonia antarctica*] to a small stream, which was also arched over by them **[painting 774]**.[70] Their stems were green with moss and parasites, wire-grass [*Aristida behriana*], ferns, and creepers; over them was a lovely tecoma [*Pandorea pandorana*], with white flowers tipped with deep red purple, hanging among its glossy green leaves. There was a delicate moss on the ground with flowers like Maltese crosses, and tiny white and purple violets [*Viola hederacea*] without scent. The musk-tree [*Olearia argophylla*] was just coming into masses of white bloom, its leaves magnificent, polished like those of the great American magnolia with white linings' **[Fig. 25, painting 761]**.[71]

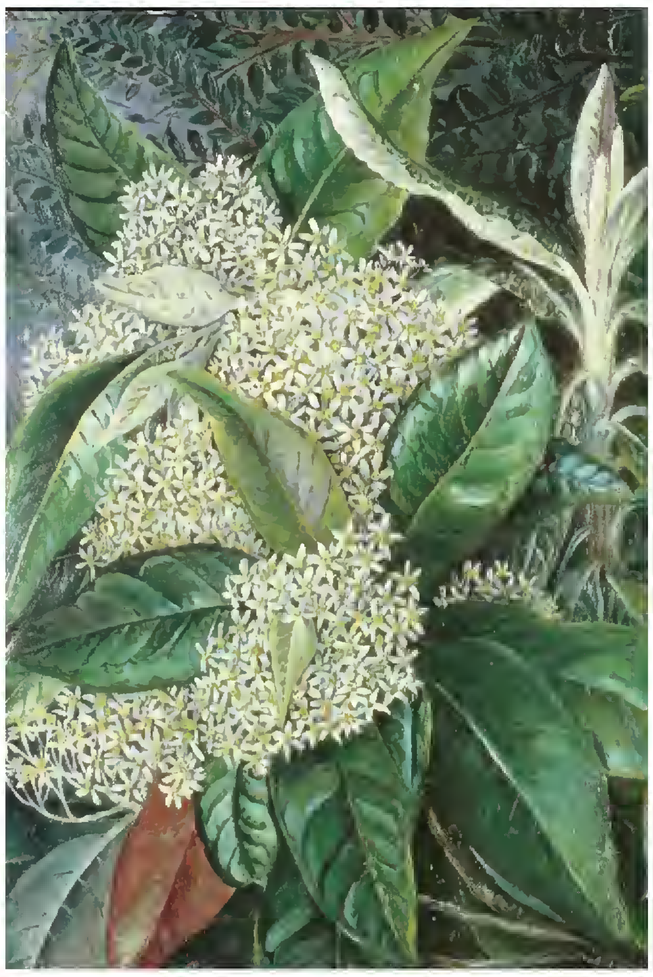


Fig. 25. *761. Musk Tree and Background of Evergreen Beech, Victoria*. Oil on board, 47 x 33.8 cm. *Nothofagus cunninghamii* (Hook.) Oerst. (leaves, background); *Olearia argophylla* (Labill.) F.Muell. ex Benth. [North's musk-tree] (foreground). © Royal Botanic Gardens, Kew.

North explored the Fernshaw area **[painting 746]**,[72] and on 5 November observed that 'the leaves of those amygdalina gums [*Eucalyptus regnans*] were much larger and darker in colour than the other sorts I had met with; its young shoots were copper-coloured, and the stems were just peeling off their old bark, showing all sorts of delicate gray and red brown tints. The tree-ferns (chiefly dicksonias) [*Dicksonia antarctica*] were unfolding their golden crowns of huge crooks. Every step brought me to fresh pictures, but it was impossible to give any idea of the prodigious height, in the limited space of my sheets of paper' **[painting 786]**.[73] She continued: 'A woodman told me that he had often felled trees over 400 feet high. "When they was down you could easily stump them off, and there could be no mistake about that," he said. The highest the Baron [Ferdinand von Mueller] measured was 365 feet, and I painted that very tree, a white gum **[Fig. 26, painting 758]**. There are over three hundred of these giant trees. I painted a lyre-bird's nest wedged between two tree-ferns, four feet from the ground, made of great dry fern-leaves' **[painting 747]**.[74] The scene depicted in fig. 26 is a tall *E. regnans* that, according to North, was measured by Baron von Mueller. A very large specimen of *E. regnans* at Mt. Monda near Fernshaw was later, in 1895, named as the 'Mueller Tree' by the botanist A. D. Hardy (Mace 1996). However, it cannot be ascertained if the tree depicted by North and the Mueller Tree were the same trees. The Mueller Tree was renamed as the Furmston Tree in the 1930s, after it was supposedly rediscovered by Harold Furmston, and as of 1996 was standing. The present condition of that tree is not known.

---

[68] *Recollections*, vol. 2, p. 142; www.kew.org/mng/gallery/752.html.

[69] *Recollections*, vol. 2, p. 144; www.kew.org/mng/gallery/777.html.

[70] www.kew.org/mng/gallery/774.html.

[71] *Recollections*, vol. 2, pp 144–145.

[72] www.kew.org/mng/gallery/746.html.

[73] *Recollections*, vol. 2, p. 145; www.kew.org/mng/gallery/786.html.

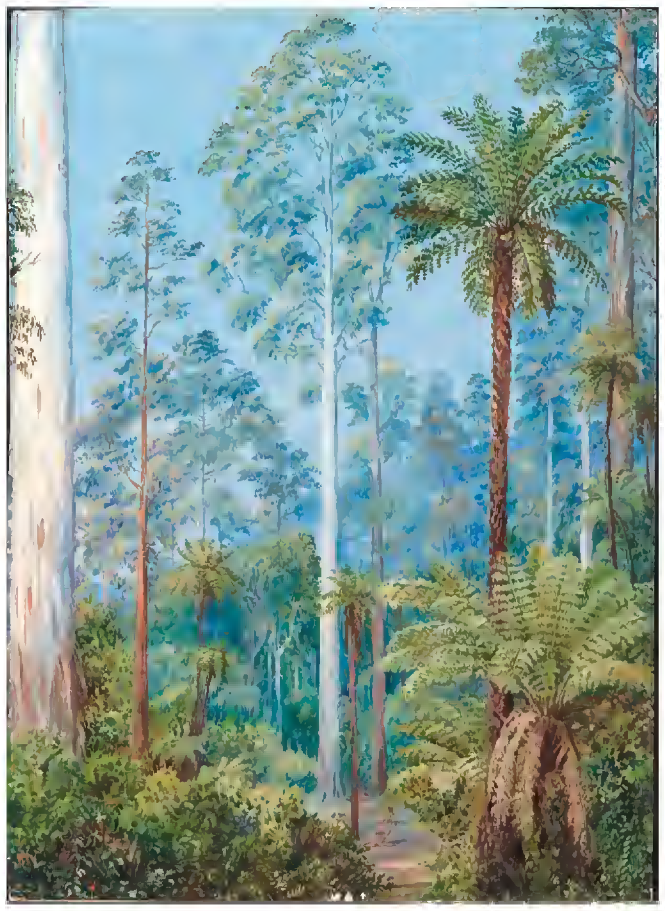


Fig. 26. *758. Fernshaw, Victoria.* Oil on board, 47.2 x 34.2 cm. *Eucalyptus regnans* F.Muell. (left and centre); *Cyathea* sp.(tall tree fern, middle ground); *Dicksonia antarctica* Labill. (short tree fern, foreground); *Macropus* sp. (Wallaby). © Royal Botanic Gardens, Kew.

On about 10 November, North returned to Melbourne. She contemplated the impact that colonisation was having on the environment and wrote that 'it is curious how we have introduced all our weeds, vices, and prejudices into Australia, and turned the natives (even the fish) out of it'.[75] It can be speculated that North's reference to the removal of fish species may relate to the introduction of trout into Australian streams commencing in the 1860s. The trout were able to out-compete the native species and were having a considerable impact on the Australian fish fauna (Cadwallader 1996).

Western Australia

North departed Melbourne on *S.S. Malwa* on 11 November destined for Albany, Western Australia.[76] She had intended to meet Richard Schomburgk, Director of the Adelaide Botanic Gardens, but bad weather prevented her landing at Adelaide.[77] She arrived in Albany on 18 November (**Fig. 27**).[78] Here she was hosted by the Australian flower painter Ellis Rowan who was then on an expedition to paint Western Australian flowers (Hazzard 1984). North wrote that Rowan 'introduced me to quantities of the most lovely flowers - flowers such as I had never seen or even dreamed of before **…** so I stayed on at Albany till the carriage came, and found abundance to do. The garden of our little house led right on to the hillside at the back, and the abundance of different species in a small space was quite marvellous. In one place I sat down, and without moving could pick twenty-five different flowers within reach of my hand. The banksias [*Banksia grandis*, **painting 784**][79] were quite marvellous, their huge bushy flowers a foot in length, and so full of honey that the natives were said to get tipsy sucking them. The whole country was a natural flower-garden' [**Fig. 28, painting 750]**.[80]

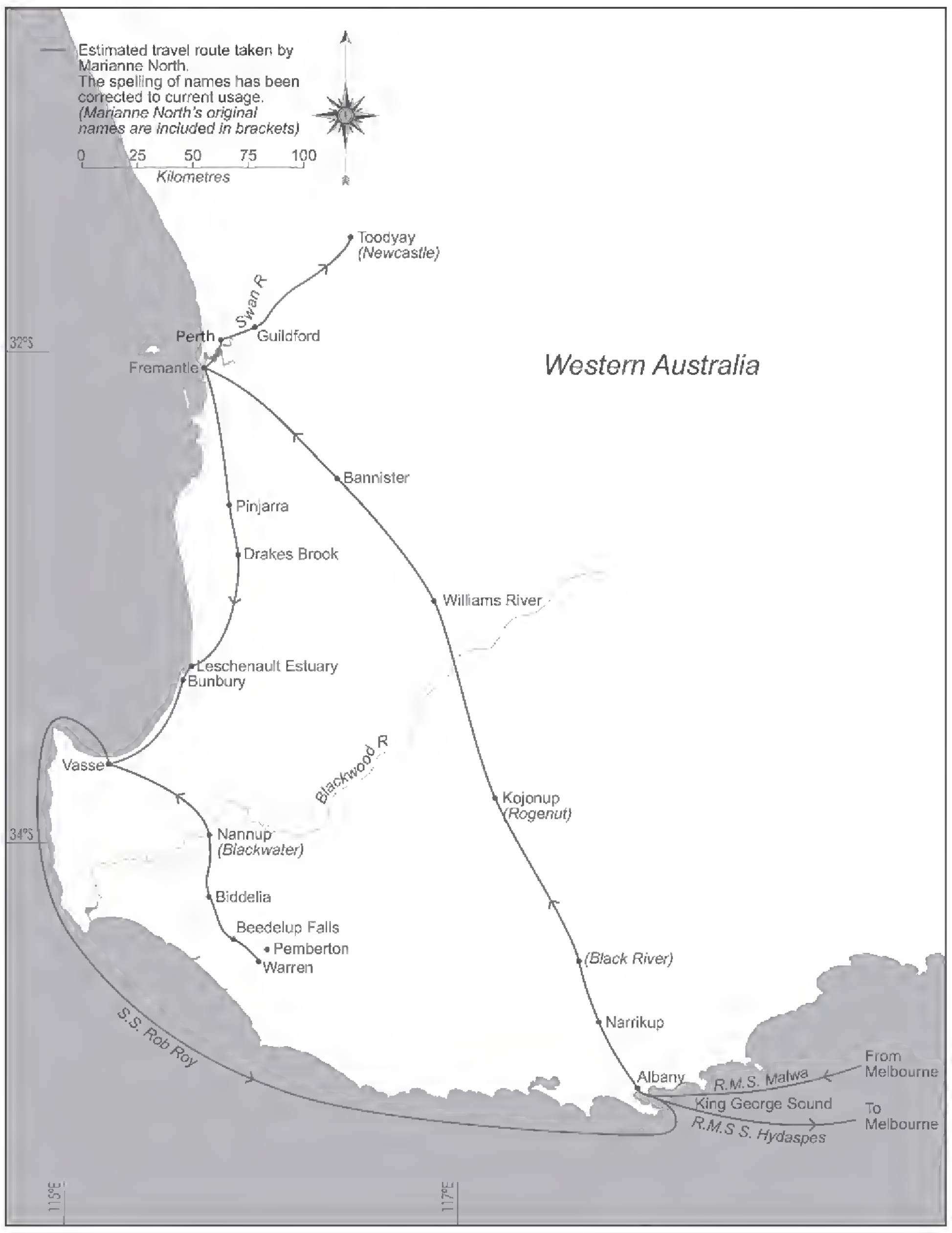


Fig. 27. Travel route taken by Marianne North in Western Australia, 1880–1881. Prepared by Claire Burton.

---

[74] *Recollections*, vol. 2, p. 145; www.kew.org/mng/gallery/747.html.

[75] *Recollections*, vol. 2, p. 147.

[76] *Argus*, 13 Nov. 1880, p. 6, 'Shipping intelligence'.

[77] *Express and Telegraph*, 15 Nov. 1880, p. 2, 'Glenelg Shipping'.

[78] *Herald*, 20 Nov. 1880, p. 2, 'Outports-Arrivals. Albany'.

[79] www.kew.org/mng/gallery/784.html

[80] *Recollections*, vol. 2, pp 148–149.

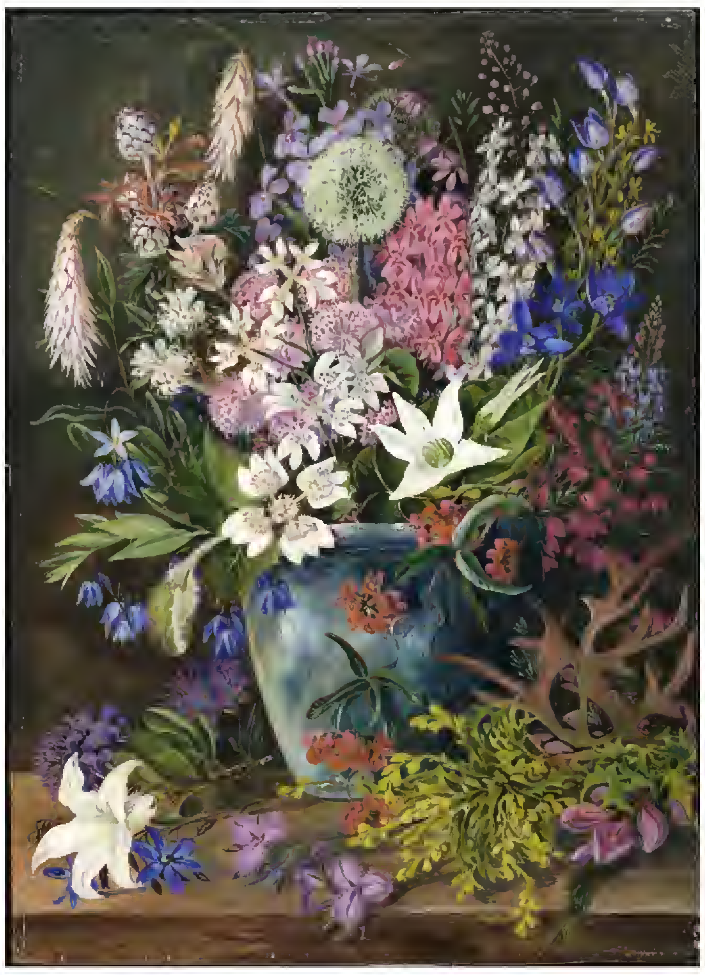


Fig. 28. *750. Wild Flowers of Albany, West Australia.* Oil on board, 47.3 x 34 cm. Clock-wise from top left: *Petrophile diversifolia* R.Br. (buds) (white flowers); *Johnsonia lupulina* R.Br. (white flowers); *Isotoma hypocrateriformis* (R.Br.) Druce (mauve flowers); *Dasypogon bromeliifolius* R.Br. (cream flowers); *Tetratheca affinis* Endl. (pink flowers); *Stylidium* spp. (pink, white, yellow and blue flowers); *Thelymitra crinita* Endl. (blue buds and flowers); *Cosmelia rubra* R.Br.(red/crimson flowers); *Boronia molloyae* J.Drumm. (red flowers); *Synaphea polymorpha* R.Br.(yellow flowers); *Gompholobium scabrum* Sm. (pink flowers); *Thysanotus* sp. (pink flowers); *Agrostocrinum scabrum* (R.Br.) Baill. (blue flowers); *Anthocercis viscosa* R.Br. (white flowers); *Mirbelia dilatata* R.Br. ex Dryand. (mauve flowers); *Billardiera heterophylla* (Lindl.) L.Cayzer & Crisp (blue flowers); *Kennedia coccinea* (Curtis) Vent. (orange/red flowers); *Xanthosia rotundifolia* DC. (white flowers); *Pimelea rosea* R.Br. (pink flowers); *Petrophile diversifolia* R.Br. (open white flowers). © Royal Botanic Gardens, Kew.

Rowan (1905) was later to reminisce about her time with North: 'I became her devoted admirer, and she became the pioneer of my ambition. A world-wide traveller in search of specimens, her description of her adventures was so vivid, so graphic, so thrilling in its prospects of wider fields that I became infected, stimulated by an example and a result beyond dreams successful. Retiring to my room that night, after my conversation with her, I resolved to do what she had done. I would travel the world in search of flowers rare and wonderful, travel countries inaccessible, as well as those which offered difficulties only imaginary'.

On about 25 November, North departed Albany to travel overland directly to Perth. In the vicinity of Narrikup she observed 'a group of hakeas [*Hakea cucullata*], like a tall hollyhock with leaves like scallop shells, perfect cups growing close together round and round the stem. Every leaf had a flower or seed-pod resting in it; the flowers were pink, but the chief peculiarity was, that every spike of leaves was gradually shaded downwards —the leaves at the top salmon pink, those next yellow and orange, and so into brightest green, blue-green, and purplish gray. It is one of the remarkable plants of the world' **[Fig. 29, painting 791]**.[81]

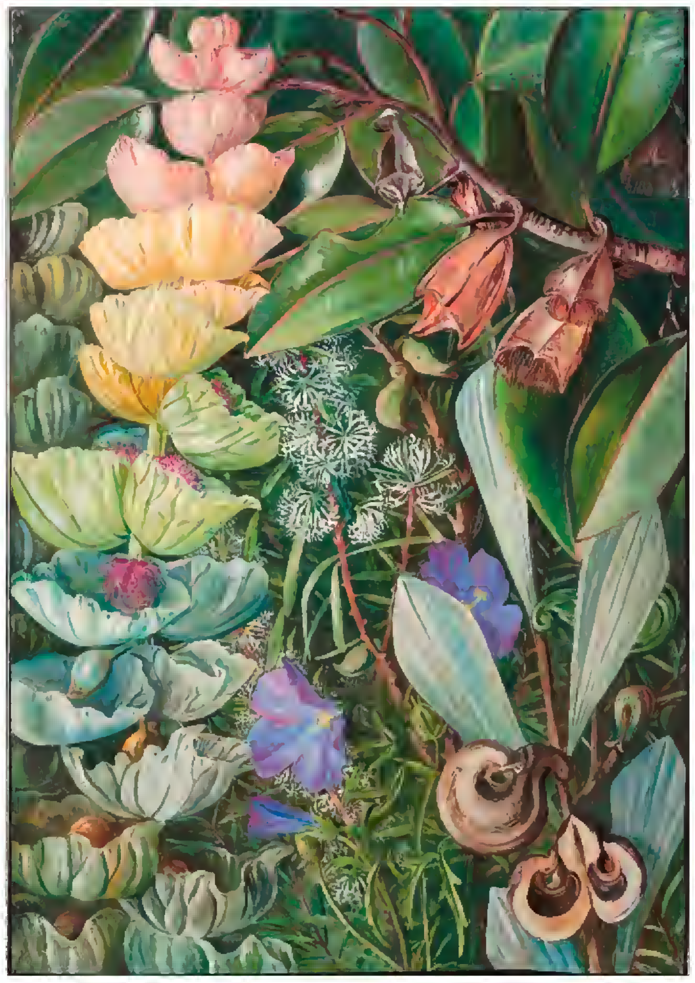


Fig. 29. *791. West Australian Shrubby Vegetation.* Oil on board, 50.5 x 35.4 cm. *Hakea cucullata* R.Br. [North's Hakea] (green to pink leaves); *Eucalyptus tetraptera* Turcz. (red capsules); *Hakea cyclocarpa* Lindl. (brown fruits); *Alyogyne huegelii* (Endl.) Fryxell (blue flowers); *Hakea falcata* R.Br. (white flowers). © Royal Botanic Gardens, Kew.

On about 27 November, North reached Williams River. Here she observed 'some sandal-wood (*Fusanus spicatus*) [*Santalum acuminatum*] trees **[painting 765]**,[82] one of the gums, which has the same scent and qualities as the real sandal-wood; this is exported to India and China to take its place in the manufacture of boxes and other pretty things. It grows to the size of an English apple-tree, and is hung over with a mistletoe [*Amyema* sp.] which mimics its own leaves exactly **[painting 734]**[83]. On that day, too, I shall never forget one plain we came to, entirely surrounded by the nuytsia or mistletoe trees [*Nuytsia floribunda*], in a full blaze of bloom. It looked like a bush-fire without smoke. The trees are, many of them, as big as average oaks in our hedgerows at home, and the stems are mere pith, not wood. The whole is said to be a parasite on the root of another tree (probably the *Banksia*)' **[painting 764; painting 766]**.[84] Near Bannister, she continued: 'We passed several hollows filled with the "smoke-plant," [*Conospermum* sp.] looking like mist on the ground, and many curious rushes [Cyperaceae spp or Restoniaceae spp], sundews [*Drosera* sp.], and bushes of exquisite scarlet grevillea, which looks like polished coral; blue veronicas, with lovely sollyas [*Billardiera heterophylla*] and kennedyas [*Kennedia* spp] over them, and plenty of grass-trees [*Xanthorrhoea* sp.], varied by kingia [*Kingia*

---

[81] *Recollections*, vol. 2, p. 150.

[82] www.kew.org/mng/gallery/765.html.

[83] www.kew.org/mng/gallery/734.html.

[84] *Recollections*, vol. 2, p. 153; www.kew.org/mng/gallery/764.html; www.kew.org/mng/gallery/766.html.

australis], a still more striking plant, with a crown of balls like drum-sticks on its head. The grass-trees at a distance, and especially when seen with their backs to the light, were wonderfully like the "black boys," with bits of skin hanging from their shoulders, and wild wigs, their heads so much too big for their bodies, and spears held up high above them. The banksia-trees [*Banksia attenuata*] were then covered with their young leaves and shoots of rich yellow, brown, or white, and the native wigwams of bark or leaves looked picturesque under them **[Fig. 30, painting 741]**.[85]

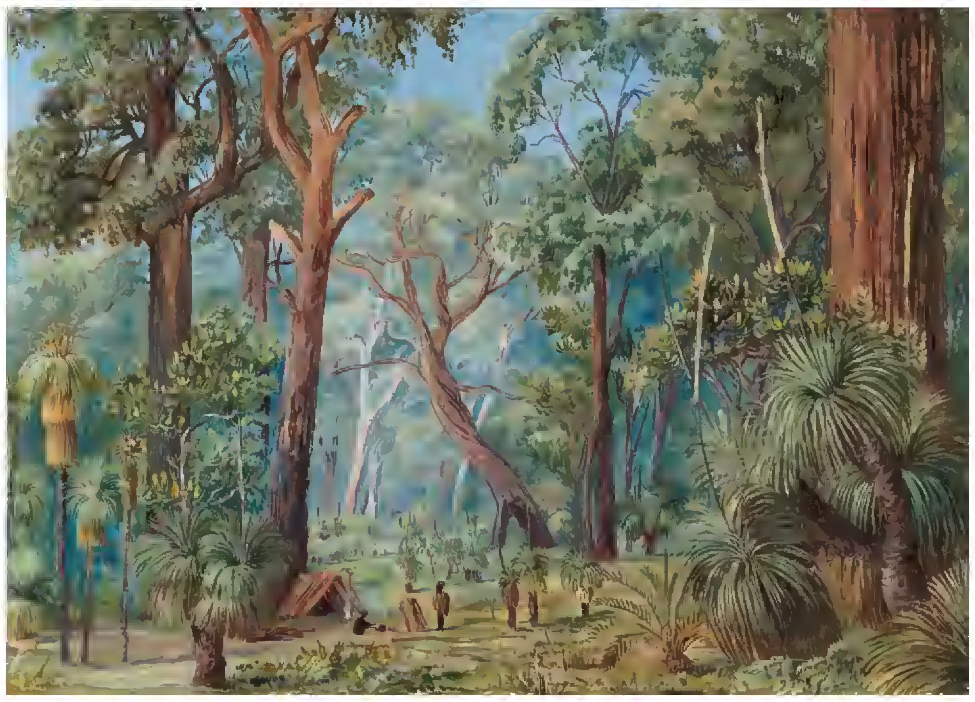


Fig. 30. *741. Scene in a West Australian Forest.* Oil on board, 34.3 x 47.4 cm. *Eucalyptus marginata* Donn ex Sm. [North's jarrah] (tallest trees); *Eucalyptus megacarpa* F.Muell. (white bark, distance); *Banksia grandis* Willd. [North's banksia-tree] (bottle brush, yellow flowers, middle distance); *Xanthorrhoea preissii* Endl. (grass trees, right foreground); *Macrozamia riedlei* (Fisch. ex Gaudich.) C.A.Gardner (stemless cycad, right foreground); *Kingia australis* R.Br. (thin stemmed grass trees, left middle distance). © Royal Botanic Gardens, Kew.

On about 30 November, North arrived at Fremantle as the guest of John and Margaret Forrest. North recalled that he was a 'former explorer and amateur botanist and then Acting Superintendent of Convicts at Fremantle, and she a plant illustrator and collector for von Mueller'. North continued that 'the sea at Freemantle was edged with delicate little shrubby plants, then out of flower, but their leaves and twigs had a whitish look [*Acacia cyclops*], and seemed to harmonise with the dazzling white sand in a way that green leaves would not have done' **[painting 753]**.[86] This painting is a view looking west from Monument Hill over the mouth of the Swan River with Rottnest Island in the far distance.[87] North depicted a galah feeding on the flowers of *Eucalyptus marginata* **[painting 762]**[88] and also found the kangaroo paws of great interest, and noted that 'Mrs. Forrest also gave me to paint a bit of the black velvet "kangaroo's foot" with yellow satin lining [*Anigozanthos humilis*], from Champion Bay' **[painting 740]**.[89]

From Fremantle, North travelled to Perth on about 6 December where she was the guest at Government House of Lady Robinson, wife of the Governor Sir William Robinson. Later, on 12 December, with Margaret Forrest, North drove to Newcastle [Toodyay], as word had been received that *Eucalyptus macrocarpa* was in flower.[90] North wrote: 'But when I heard that the *Eucalyptus macrocarpa* was to be seen in flower at Newcastle, horses were again ordered for me, and I was sent over there … we went only too fast through all the forest wonders, and I screamed with delight when the small tree came in sight close to Mrs. H.'s [Mrs Harper] house. Every leaf and stalk was pure floury white, and the great flowers (as big as hollyhocks) of the brightest carnation, with gold ends to their stamens' **[Fig. 31, painting 751]**.[91] Mrs Harper was the widow of Charles Harper, former barrister and later clergyman in the parish of Newcastle. Mueller (1879–1884), in his *Eucalyptographia*, referred to North's painting of *Eucalyptus macrocarpa* that he was shown by North on her return to Melbourne. Mueller wrote that the 'accomplished Miss North prepared, during her recent stay in West-Australia, among the oil-paintings illustrative of indigenous vegetation, also a picture of this Eucalypt for the art-gallery, which she generously provides for the large museum of the Royal Botanic Garden of Kew, under Sir Joseph Hooker'.

The only known herbarium specimen collected by North in Australia is that of *E. macrocarpa* which she acquired from the plant she painted at Toodyay [North's Newcastle], Western Australia (Maroske 2014). The specimen is now in the National Herbarium of Victoria (**Fig. 32**). North later wrote of how this specimen found its way there: 'Baron von Mueller was excited over my paintings of the *Nuytsia* [*Nuytsia floribunda*] and the *Eucalyptus macrocarpa,* which he had named, but had never seen in flower. When I showed him the bud with its white extinguisher cap tied over it, which I was saving for Kew, he said, "Fair lady, you permit I take that" and calmly pocketed it!'.[92] Mueller then incorporated the specimen into his Melbourne herbarium.

An article about North's interest in *Eucalyptus macrocarpa* appeared in a local newspaper, and stated that 'during her short sojourn in Newcastle, where Miss North remained only two or three days, she was the guest of Mrs. Harper, in whose garden she was fortunate in meeting with a beautiful specimen of the Dwarf *Eucalyptus* in blossom, with the gorgeousness of which this lady is said to have been particularly struck. The sketch of it will make an interesting addition to her collections.[93]

---

[85] *Recollections*, vol. 2, p. 154.

[86] *Recollections*, vol. 2, p. 155; www.kew.org/mng/gallery/753.html.

[87] Personal communication, Anne Brake & Pam Harris, Fremantle Historical Society.

[88] www.kew.org/mng/gallery/762.html.

[89] *Recollection*, vol. 2, pp 155–156; www.kew.org/mng/gallery/740.html.

[90] *West Australian*, 17 Dec. 1880, p. 3, 'Country letters'.

[91] *Recollections*, vol. 2, p. 156.

[92] *Recollections*, vol. 2, p. 168.

[93] *Eastern Districts Chronicle*, 24 Dec. 1880, p. 2, 'Local Districts and General Topics.'

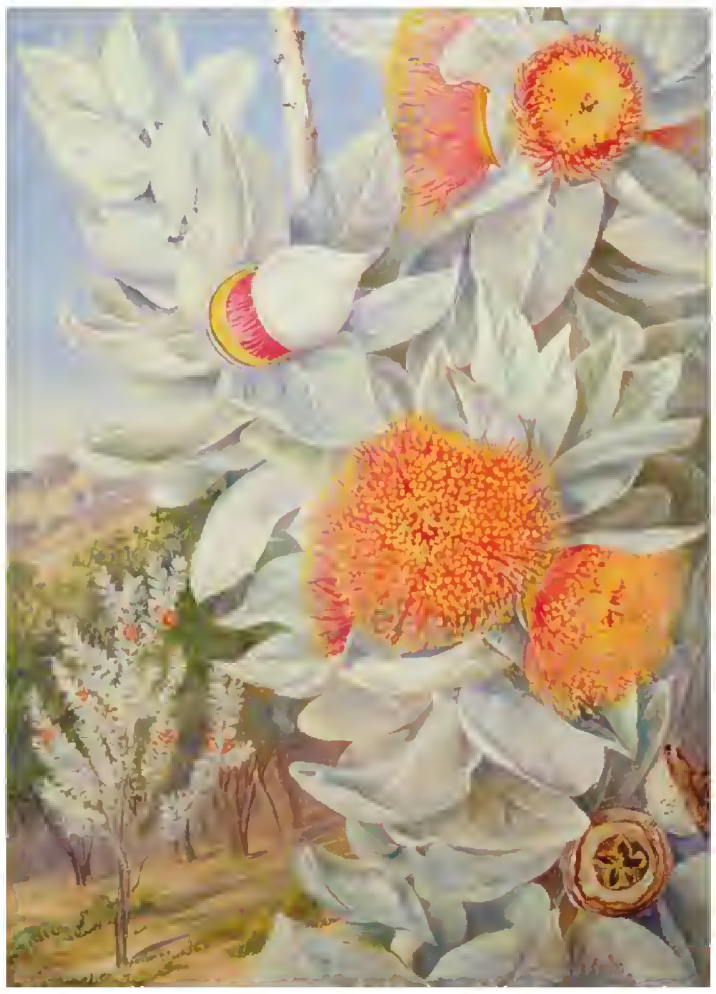


Fig. 31. *751. Foliage, Flowers, and Seed-vessels of a Rare West Australian Shrub.* Oil on board, 47.3 x 33.8 cm. *Acacia acuminata* Benth. [North's jam-tree] (far distance); *Eucalyptus macrocarpa* Hook. (foreground). © Royal Botanic Gardens, Kew.

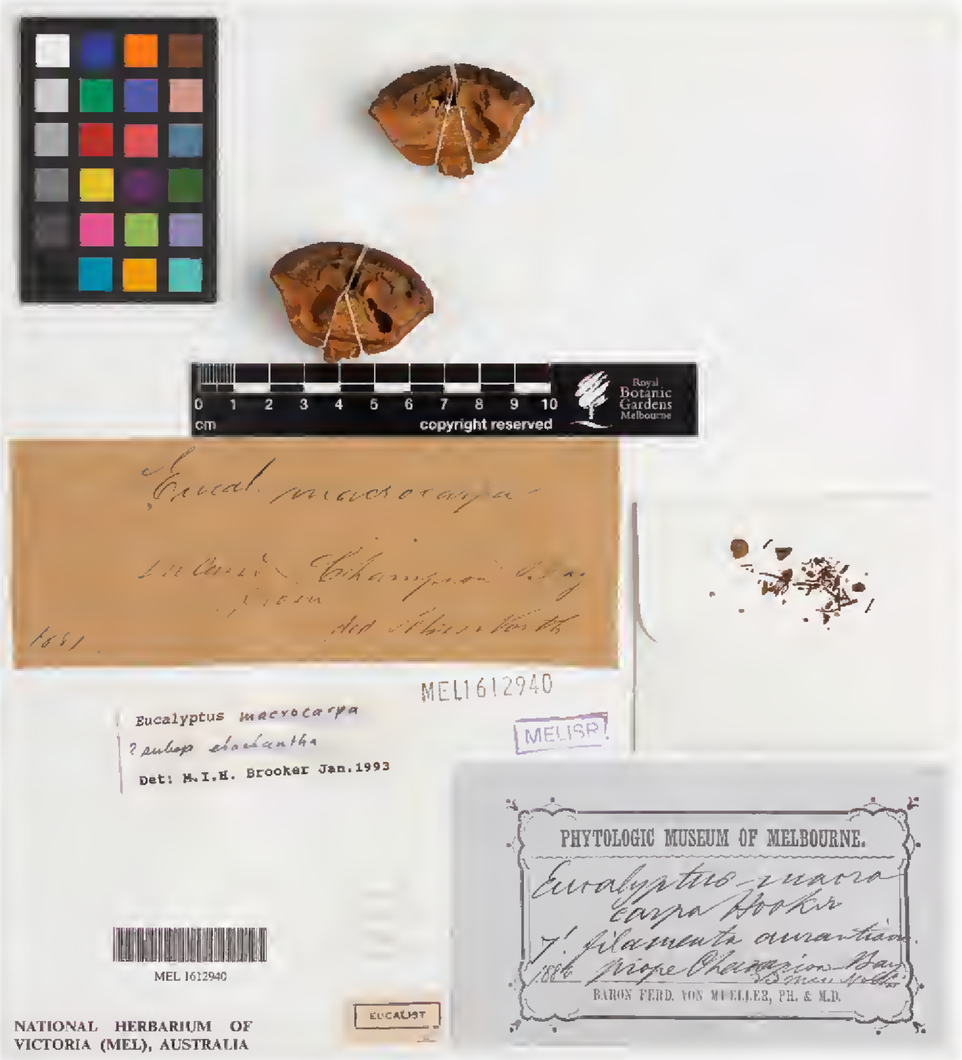

0 1 2 3 4 5 6 7 8 9 10
cm
copyright reserved
Royal Botanic Gardens Melbourne
MEL1612940
Eucalyptus macrocarpa
Det: M.I.H. Brooker Jan.1993
MEL1SP
PHYTOLOGIC MUSEUM OF MELBOURNE.
BARON FERD. VON MUELLER, PH. & M.D.
MEL 1612940
NATIONAL HERBARIUM OF VICTORIA (MEL), AUSTRALIA
EUCALIST

Fig. 32. Specimen of *Eucalyptus macrocarpa* collected by Marianne North in Western Australia. MEL1612940, designated as *Eucalyptus macrocarpa* var. *elachantha*. Reproduced with permission of the Royal Botanic Gardens Victoria.

North and Forrest returned to Perth on about 14 December passing through Guilford where they visited Forrest's brother Samuel Hammersley. Here North noted that 'the great attraction to me was a bush of white grevillea [*Grevillea leucopteris*], which had come from Champion Bay originally **[painting 780]**.[94] It looked like a gigantic lavender bush, with a woody trunk, and stick-like branches all round, bearing lovely cream-coloured waxy bunches of flowers a yard above the leaves. At night the scent was so disagreeable that everyone killed it, and this plant was the only specimen left. Mrs. F. [Margaret Forrest] had brought me on purpose that I might get a bit and see it growing.[95]

On 16 December, North returned to Perth but soon after continued her travels through the coastal areas to the south. Near Pinjarra she noted that 'we passed through glorious forests of big gums and mahogany trees, and plains of paper-bark trees [*Melaleuca* spp.], with their curious white twisted trunks and velvety green heads, sometimes sprinkled with small white flowers. We saw also the native pears [*Xylomelum angustifolium*], with long bunches of greenish-white flowers, and gray velvety fruit, the younger ones almost rosy, like the winged seeds inside. We passed swamp banksias [*Banksia littoralis*] with twisted gray stems like olives, and miles of grass-trees [*Xanthorrhoea* sp.] and kingias [*Kingia australis*], looking like frosted silver in the mid-day sun … I found quantities of a lilac satin flower about the size of a primrose, with oily grassy leaves. Picking it made my fingers wet, though it was growing in the driest white sand, among other dry things, and was said to be *Byblis gigantea,* a sort of sundew mentioned by Darwin, but not yet seen in England' **[painting 755]**.[96]

On 18 December, North passed through the Waroona area and noted that 'the grass-trees [*Xanthorrhoea* sp.] had a dozen heads of flowers from one trunk, each head bearing its long flower-spike. The zamias [*Macrozamia riedlei*] were on stems or stocks a yard high' **[painting 756]**.[97] From Waroona, North travelled past the Leschenault Estuary to Bunbury. Her transit through Bunbury was reported in a local newspaper article, and stated that 'Miss North, who is on a tour through our Karri forests, for the purpose of taking sketches in that locality. Miss North goes round by Vasse, Lower Blackwood, Donnelly, and the Warren, proceeding thence across the country to Albany'.[98]

Leaving Bunbury North travelled to Vasse and then eastward to Beedelup and finally to Warren River arriving there about 23 December. At Beedelup she noted a 'forest of perhaps the biggest trees in the world … I spent four delightful hours sketching or resting under those gigantic white pillars [*Eucalyptus diversicolor*], more imposing than the trees of Fernshaw; their stems were thicker and heads rounder than the amygdalina gums **[Fig. 33, painting 782]**.[99] The subject of the painting still stands (as of June 2018) near Warren River on the Old Vasse Road and has become known as the 'Marianne North Tree', an attraction for travellers and tourists (**Fig. 34**). The existing bur on the tree is very similar to that which she depicted.[100]

---

[94] www.kew.org/mng/gallery/780.html.

[95] *Recollections*, vol. 2, p. 158.

[96] *Recollections*, vol. 2, p. 159; www.kew.org/mng/gallery/755.html.

[97] *Recollections*, vol. 2, p. 159; www.kew.org/mng/gallery/756.html.

[98] *Inquirer and Commercial News*, 22 Dec. 1880, p. 3, 'Doings at Fremantle.'

[99] *Recollections*, vol. 2, p. 164.

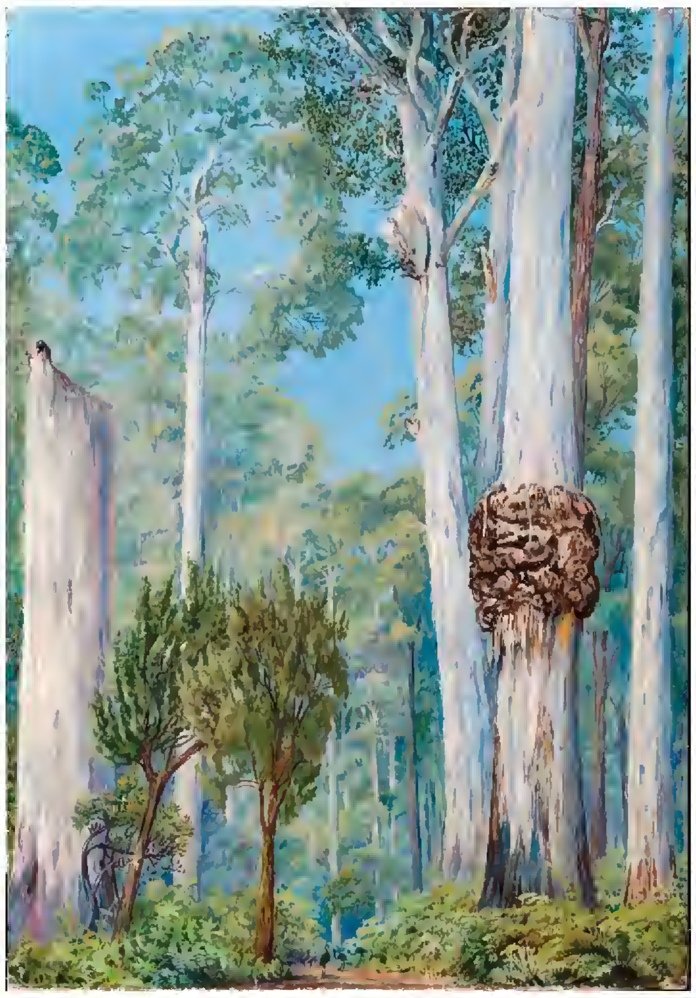


Fig. 33. *782. Karri Gums, Near the Warren River, West Australia.* Oil on board, 50.8 x 35.1 cm. *Eucalyptus diversicolor* F.Muell. (Karri) (white bark); *Allocasuarina decussata* (Benth.) L.A.S.Johnson [North's Casuarina] (tall shrubs, foreground centre); *Leucopogon verticillatus* R.Br. (low shrub, left foreground); *Macrozamia riedlei* (Fisch. ex Gaudich.) C.A.Gardner [North's zamia] (low cycads, right foreground); *Banksia* sp. (bottle brush, yellow flowers, left middle ground); *Dromaius novaehollandiae* (Latham, 1790) (Emu). © Royal Botanic Gardens, Kew.

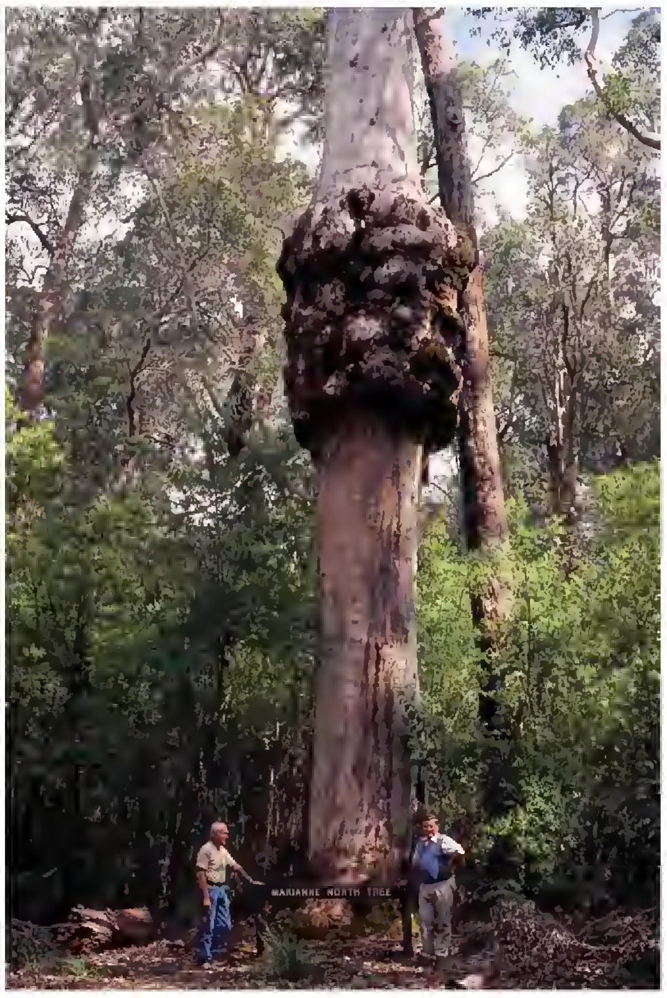


Fig. 34. The Marianne North Tree, Old Vasse Road. Photo: A.George.

North spent Christmas Day with the Brockman family at Warren River,[101] and on Boxing Day resumed painting [**painting 789**].[102] She observed that 'one lovely plant grew quite high, with its leaves arranged in stages all the way up like stars of green [*Leucopogon verticillatus*], and tiny strings of flowers or waxy berries under each leaf' [**painting 757**].[103] Of this she included a rough sketch in a letter to Joseph Hooker **[Fig. 35],** and which she described as 'a common but exquisitely graceful plant often growing as tall as myself – the leaves like green stars with delicate pink blossoms or green and white berries under them so -'.[104]

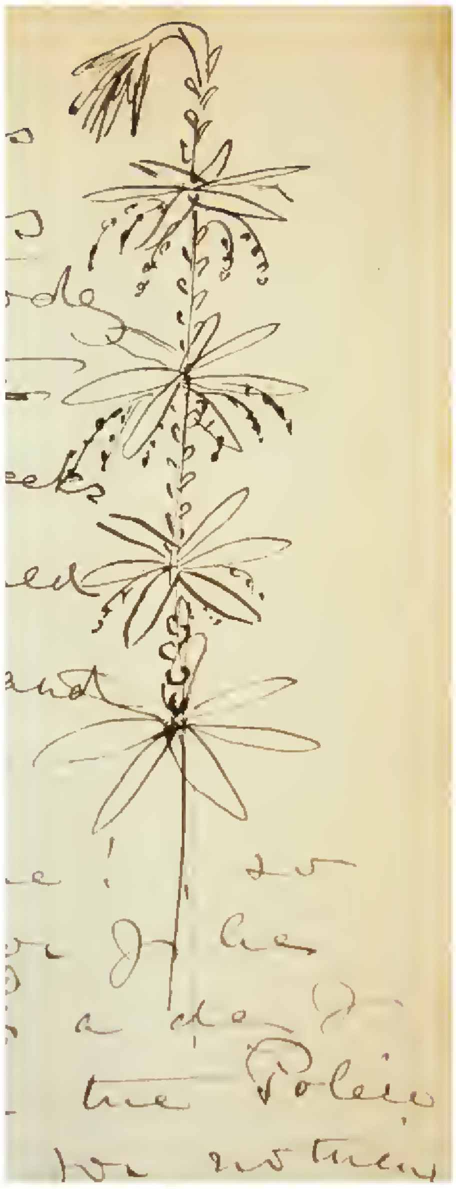


Fig. 35. *Leucopogon verticillatus* R.Br., sketched by Marianne North in a letter to Joseph Hooker, 29 December 1880, Albany, Western Australia. © Royal Botanic Gardens, Kew.

On 27 December, North returned to Vasse where she boarded the steamer *S.S. Rob Roy* to Albany where she stayed another week.[105] This was to be a very productive period, and she wrote that she was 'hard at work painting, and offended half the good people of Albany by not returning their visits … the district around is little cultivated, but abounds with rare and beautiful flowering shrubs' **[painting 729; Fig. 36, painting 775; painting 744; Fig. 37, painting 772; painting 776]**.[106]

---

[100] Personal communication, Ellen J. Hickman, Albany.

[101] M. North to A. Edwards, 7 Feb. 1881. ABE 255, Somerville College Library, Oxford University.

[102] www.kew.org/mng/gallery/789.html

[103] *Recollections*, vol. 2, p. 165. www.kew.org/mng/gallery/757.html.

[104] M. North to J.D. Hooker, 29 Dec. 1880. Royal Botanic Gardens Kew Archives, Art and Library.

[105] *Herald* (Fremantle), 25 Dec. 1880, p. 2, 'Shipping'.

[106] *Recollections*, vol. 2, p. 167; www.kew.org/mng/gallery/729.html; www.kew.org/mng/gallery/775.html; www.kew.org/mng/gallery/744.html; www.kew.org/mng/gallery/776.html.

The latter of this group of paintings is a view from Mt Melville one of the hills between which the town of Albany is nestled (**Fig. 38**). The water in the foreground is Princess Royal Harbour, the thin strip of land on the left is the isthmus to Quaranup, and King George Sound is in the distance and Bald Head is under the *Banksia coccinea*.[107]

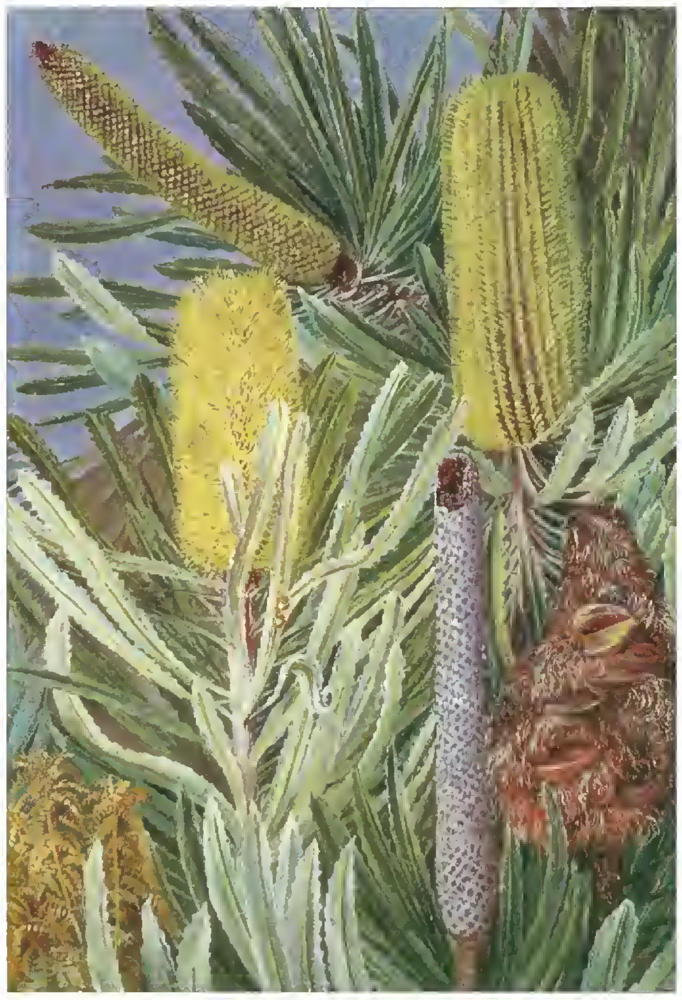


Fig. 36. *775. A West Australian Banksia*. Oil on board, 50.9 x 35.4 cm. *Banksia attenuata* R.Br. © Royal Botanic Gardens, Kew.

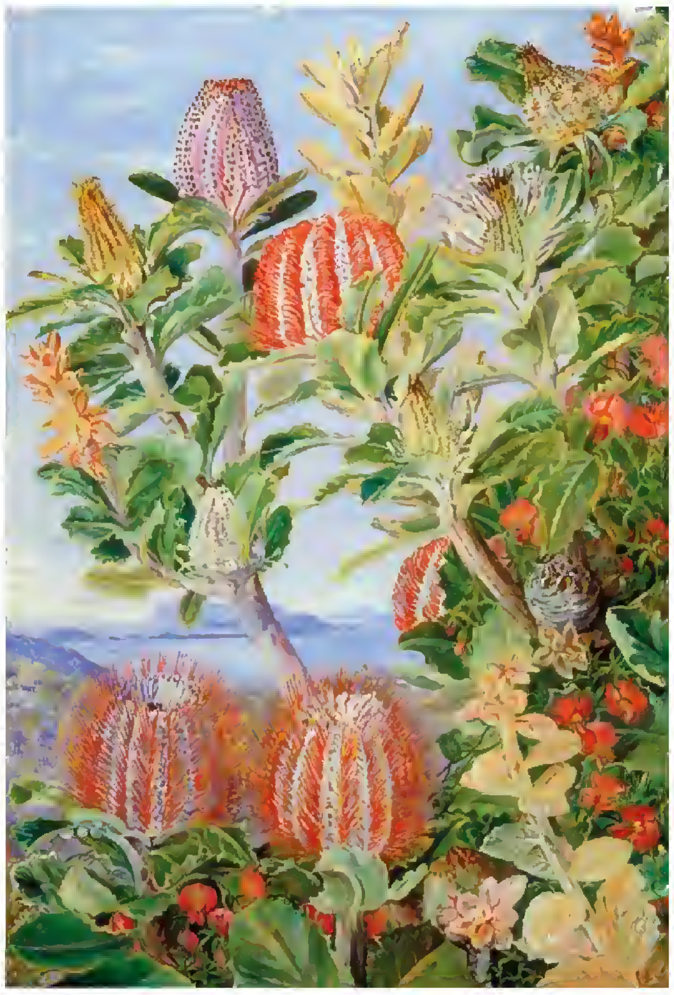


Fig. 37. *772. West Australian Vegetation*. Oil on board, 50.7 x 35.2 cm. *Banksia coccinea* R.Br. (red bottle-brush, centre); *Gompholobium polymorphum* R.Br. (red-flowered vine, right and lower centre). © Royal Botanic Gardens, Kew.

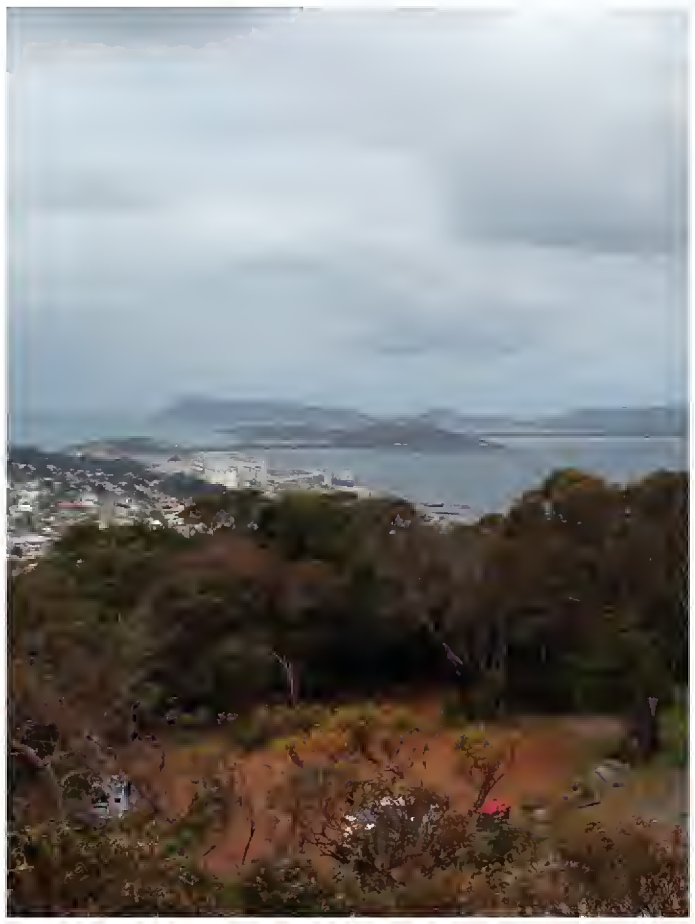


Fig. 38. Albany and Princess Royal Harbour (October 2017), the same view as depicted by Marianne North in painting *772*. Photo: A. Pettit.

North considered her Western Australian paintings to be amongst the most important of her Australian works. In correspondence to Amelia Edwards she wrote that 'the seven weeks I spent in Western Australia was the most interesting of all ... Mr. Brockmans place where I wanted to stay under the greatest giants of all Western Australia - the white gums or "Karri" with stems like polished white marble & branchless for over 200 feet - between 3 & 4 hundred feet high.[108]

On 6 January 1881, North departed Albany on *R.M.S.S. Hydaspes* and returned to Melbourne where she stayed only a few days,[109] though enough time to visit Baron von Mueller who recorded their meeting in a letter to Joseph Hooker: 'This evening I saw Miss North after her voyage to West Australia, and bid her Adieu, as she will start for Tasmania in a few days. Her paintings of W. A. vegetation are grand. I particularly admired your fathers *Euc. macrocarpa;* you probably have this brillant species at Kew, as I sent seeds repeatedly'.[110] North also made an overnight visit to Ellis Rowan at her family's residence Derriweit Heights at Mount Macedon. Here North painted her son's pet Koala [**painting 735**],[111] writing that 'he was the best of sitters, as his activity came on only at night, when we carefully fastened him into his box'.[112]

---

[107] Personal communication, Ellen J. Hickman, Albany.

[108] M. North to A. Edwards, 7 Feb. 1881. ABE 255, Somerville College Library, Oxford University.

[109] *Australasian*, 15 Jan. 1881, p. 14, 'Arrivals'.

[110] F. Mueller to J. Hooker, 15 Jan. 1881. Correspondence of Ferdinand von Mueller, Royal Botanic Gardens Victoria.

[111] www.kew.org/mng/gallery/735.html

[112] *Recollections,* vol. 2, pp 168–169.

Tasmania

On 20 January North departed Melbourne on *S.S. Flinders* and arrived in Launceston, Tasmania, later that day (**Fig. 22**).[113] She travelled on to Deloraine where she was the guest of Reverend John Evans and Mrs Evans, at the parsonage of the Anglican Church of St. Mark. Evans was rector from 1880 to 1886 (Whitefield 1897). An article about her activities was included in the local newspaper and stated that North had 'been studying and painting the flora of Australia, and intends after leaving Tasmania to take New Zealand, the Sandwich Islands, and California on her way home'.[114]

With regard to Launceston and Deloraine, North wrote: 'The country was not in the least attractive to me; it was far too English, with hedges of sweet-briar, hawthorn, and blackberry, nettles, docks, thistles, dandelions: all the native flowers (if there were any) were burnt up. One lovely flower I heard of and was taken a long drive to see. It was — a mullein! [*Verbascum thapsus*] Some of the hills looked like volcanoes, but were not, and beautiful lakes were said to lie beyond them'.[115] An article about the paintings that North did near Deloraine appeared in a local newspaper, and stated that 'one of the Western Tier, with the sylvan-banked Meander and the lovely white blossoms of the sweet-scented *Bursaria* in the foreground **[painting MNS54]**;[116] the other, a view of rugged old Quamby Bluff. She also painted a spray of flowering *Banksia*' **[Fig. 39. painting MNS48]**.[117] The first of these paintings is incorrectly labelled in the Royal Botanic Gardens Kew Library, Art and Archives as a scene of Mr Moffat's Farm, Queensland: the view is correctly of Great Western Tiers and the Meander River where it flows into Huntsman Lake.[118]

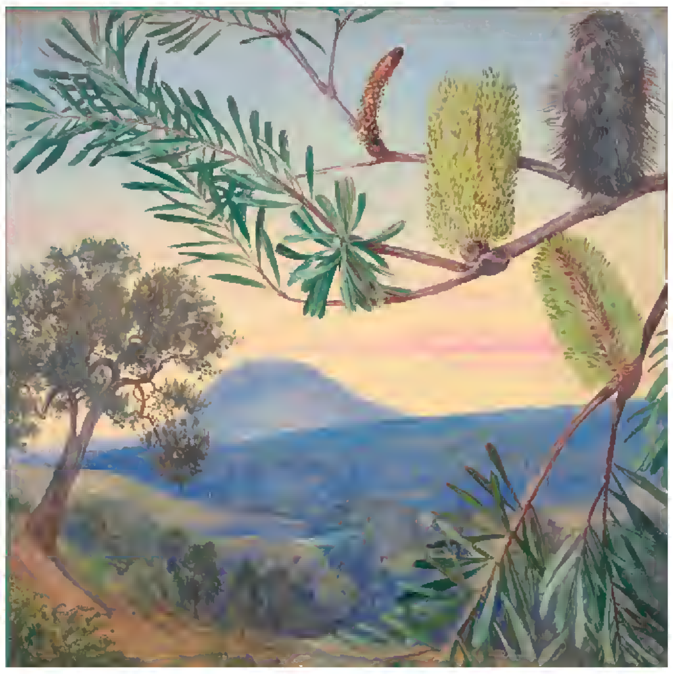


Fig. 39. *MNS48. Banksia of Tasmania.* Collection of the Herbarium, Library, Art & Archives, Royal Botanic Gardens, Kew; 1881, oil on paper, 36 x 35.8 cm. *Banksia marginata* Cav. © Royal Botanic Gardens, Kew.

North departed Deloraine on 24 January on the express train for Hobart, and on her arrival was met by Thomas Stephens, Inspector of Schools for Tasmania and an accomplished geologist and geographer. He had organised accommodation at a boarding house for North, but she was soon relocated to Government House where she was the guest of Governor John Henry Lefroy and Lady Lefroy **[painting 709]**.[119] Francis Abbott, curator of Hobart Botanical Gardens, took North to see a number of sights near Mount Wellington. Of this she wrote: 'Before I went to stay at Government House, the Head of the Gardens [Francis Abbott] came and drove me up the Huon road to the shoulder of Mount Wellington; thence we walked to St. Crispin's Well… after a rest we plunged right into the thick of it, climbing under and over the stems and trunks of fallen trees, slippery with moss, in search for good specimens of the celery-topped pine [*Phyllocladus aspleniifolius*], of which we found some sixty feet high. It was not in the least like a pine, excepting in its drooping lower branches and its straight stem: the leaves were all manner of strange shapes **[Fig. 40, painting 715]**. We also saw fine specimens of sassafras [*Atherosperma moschatum* subsp. *moschatum*] (which yields an oil rivalling the real American sassafras in value), and the dark myrtle or beech [*Nothofagus cunninghamii*] of Tasmania. Quantities of the pretty pandanus-looking plant they call grass-trees or richea [*Richea dracophylla*], really a sort of heath. The whole bunch looks like a cob of Indian corn, each corn like a grain of white boiled rice, which, again, when shed or pulled off, sets free the real flowers — a bunch of tiny yellow stamens, with the outer bracts scarlet **[painting 711]**.[120] There is also an exquisite laurel, with large waxy white flowers [*Anopterus glandulosa*]. There were many gum-trees, some of them very big, but mostly peppermint [*Eucalyptus amygdalina* or *E. pulchella*] or "stringy-bark."[*Eucalyptus obliqua*] **[Fig. 41, painting 730]**. The famous blue gum (*Eucalyptus globulus*) was rare even there: strange that this should be almost the only species known or grown in Europe' **[painting 720]**.[121] The painting in figure 40 depicts a view of Cathedral Rock from near the Pipeline Track, and was painted during a walk to St Crispin's Well.

---

[113] *Mercury* (Hobart), 22 Jan. 1881, p. 2, '[By electric telegraph.] Mount Nelson'.

[114] *Launceston Examiner*, 24 Jan. 1881, p. 2, 'A Lady Artist.'

[115] *Recollections*, vol. 2, p. 169.

[116] Paintings prefixed with MNS are held in the Royal Botanic Gardens Kew Archives, Art and Library.

[117] *Launceston Examiner*, 28 Jan. 1881, p. 3, 'Deloraine.'

[118] Personal communication, Elaine Walker.

[119] *Mercury* (Hobart), 31 Jan. 1881, p. 4, 'Fortnightly summary of news for home readers'; www.kew.org/mng/gallery/709.html

[120] www.kew.org/mng/gallery/711.html.

[121] *Recollections*, vol. 2, p. 171; www.kew.org/mng/gallery/720.html.

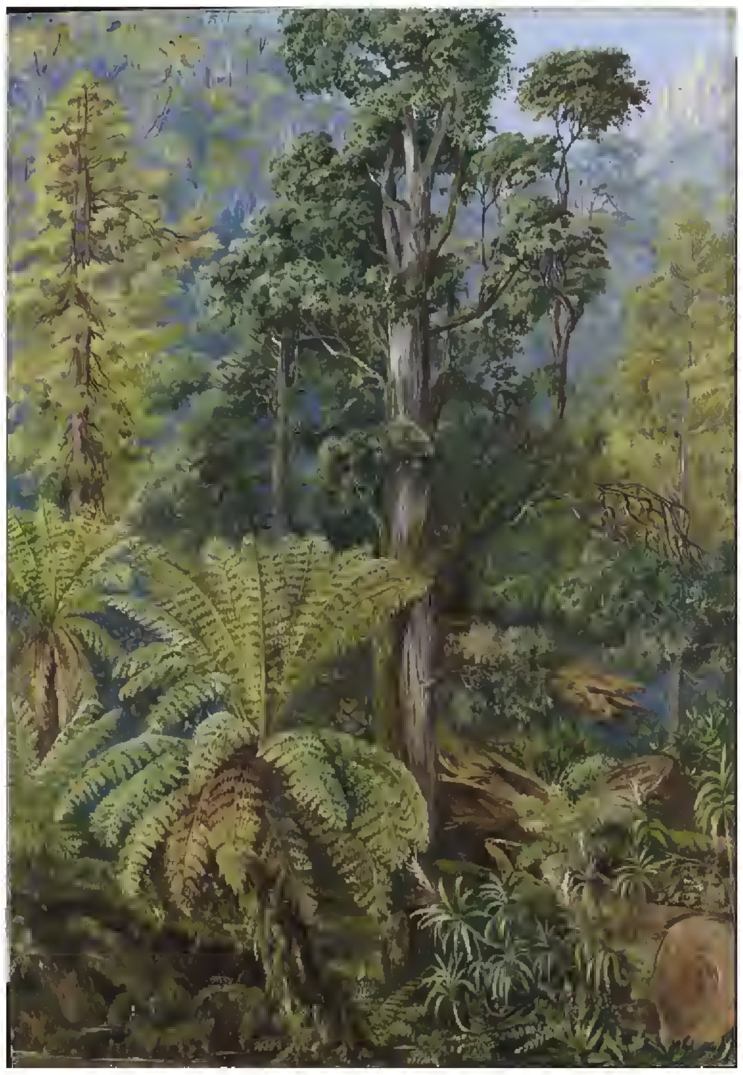


Fig. 40. *715. View in the Forest on Mount Wellington, Tasmania.* Oil on board, 50.7 x 34.9 cm. *Phyllocladus aspleniifolius* (Labill.) Hook.f. [North's celery-topped pine] (left middle ground); *Nothofagus cunninghamii* (Hook.) Oerst. [North's dark myrtle or beech] (centre); *Doryphora sassafras* Endl. (right); *Richea dracophylla* R.Br. (right foreground); *Dicksonia antarctica* Labill. (tree fern, left foreground). © Royal Botanic Gardens, Kew.

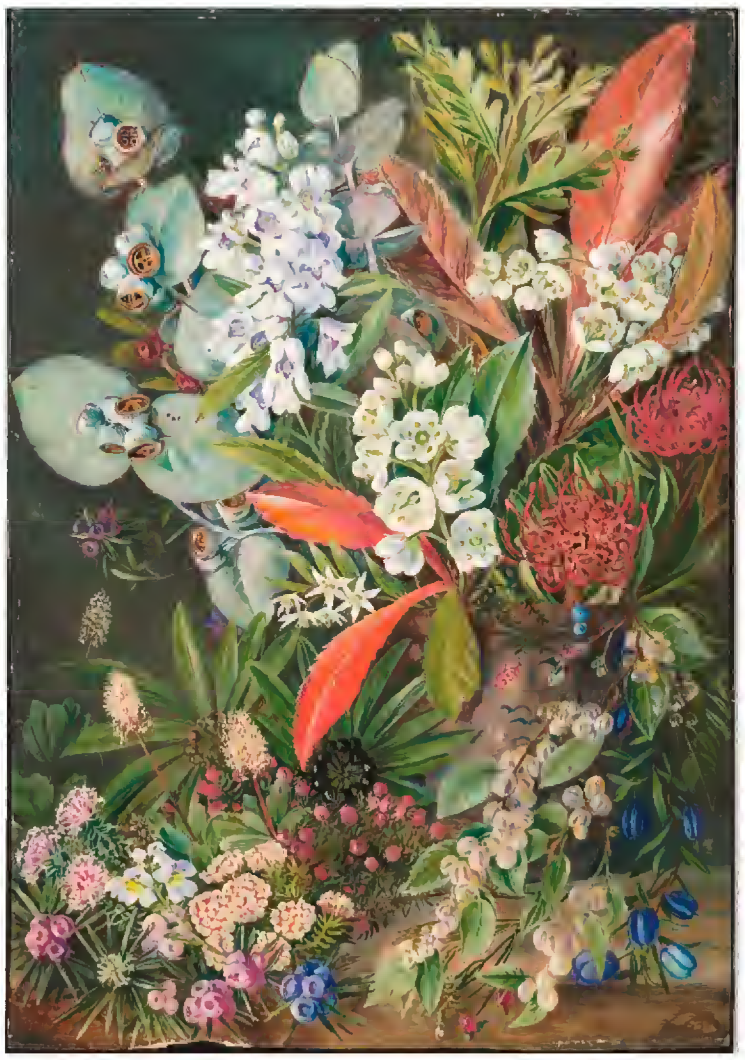


Fig. 41. *730. A Selection of Flowers from Mount Wellington, Tasmania.* Oil on board, 50.7 x 35.2 cm. Clock-wise from top left: *Eucalyptus cordata* Labill. (fruit capsules); *Prostanthera lasianthos* Labill. [North's Tasmanian lilac] (white flowers); *Phyllocladus aspleniifolius* (Labill.) Hook.f. (leaf); *Anopterus glandulosus* Labill. (white flowers); *Telopea truncata* (Labill.) R.Br. (red flowers); *Trochocarpa thymifolia* (R.Br.) Spreng. (pink flowers); *Billardiera longiflora* Labill. (purple-blue flowers); Unknown sp.; *Exocarpus cupressiformis* Labill. (red fruit); *Tasmannia lanceolata* (Poir.) A.C.Sm.(black fruit); *Leptocophylla juniperina* (pink fruit); *Ozothamnus ledifolius* (A.Cunn. ex DC.) Hook.f. (pink flowers); *Cyathodes glauca* Labill. (blue/pink/white fruit); *Euphrasia collina* R.Br. (white/yellow flowers); *Pimelea nivea* Labill. (pink flowers); *Bellendena montana* R.Br. (white/pink flowers on long stem); *Drymophila cyanocarpa* R.Br. (white flowers with six petals). © Royal Botanic Gardens, Kew.

North made two excursions to Mount Wellington. On about 28 January she accompanied Judge William Lambert Dobson, when she wrote: 'Another day I scrambled up a staircase of fallen trees and tree-fern trunks, by the bed of a half-dry stream, for 1500 feet, till we reached the first ridge of the mountain… after that I was led by Judge D. and his son to the foot of the basalt cliffs under the top, and was shown many pretty berries and flowers peculiar to the mountain' **[Fig. 42, painting 733]**.[122] The view depicted was of the Organ Pipes, Mt Wellington, looking north-west from Hall's Saddle, near the site of Red House where North stayed (**Fig. 43**). The road in the near distance is Huon Road.[123] In correspondence to Amelia Edwards, North wrote that she had 'been on two expeditions on that wonderful road & up into the crannies of Mount Wellington. I have already painted some of its more remarkable flowers & berries & trees.[124]

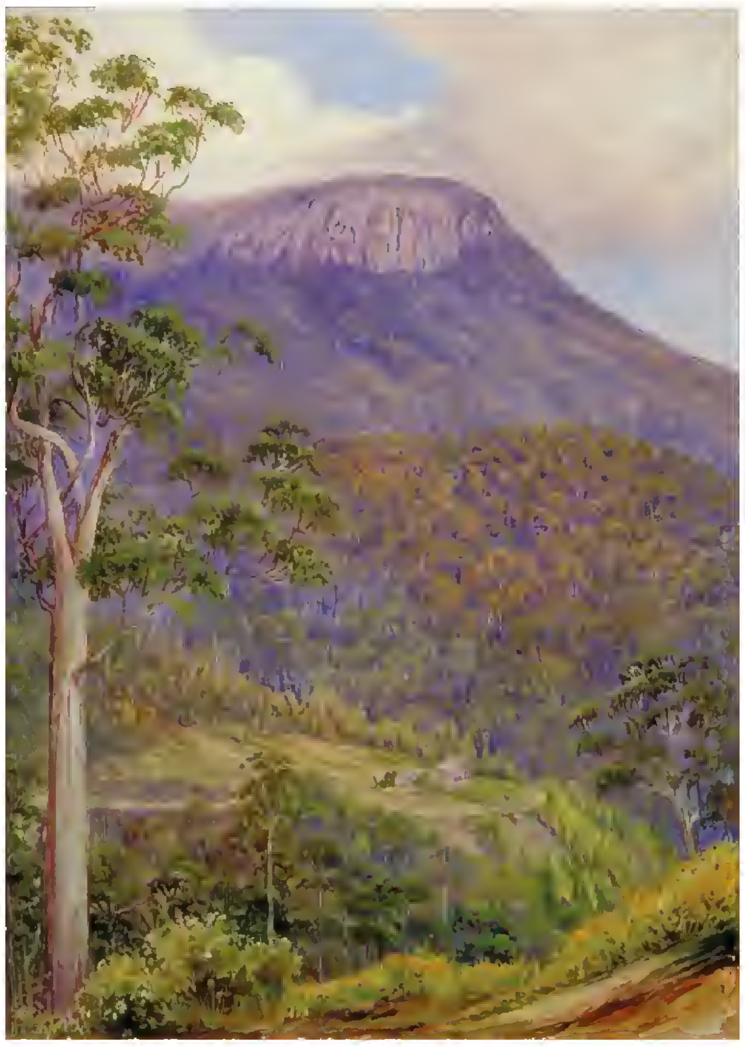


Fig. 42. *733. View of the "Organ Pipes," Mount Wellington, Tasmania.* Oil on board, 35.6 x 25.4 cm. *Eucalyptus* sp. © Royal Botanic Gardens, Kew.

---

[122] *Recollections*, vol. 2, pp 171–172.

[123] Personal communication, Axel von Krusenstierna.

[124] M. North to A. Edwards, 7 Feb. 1881. ABE 255, Somerville College Library, Oxford University.

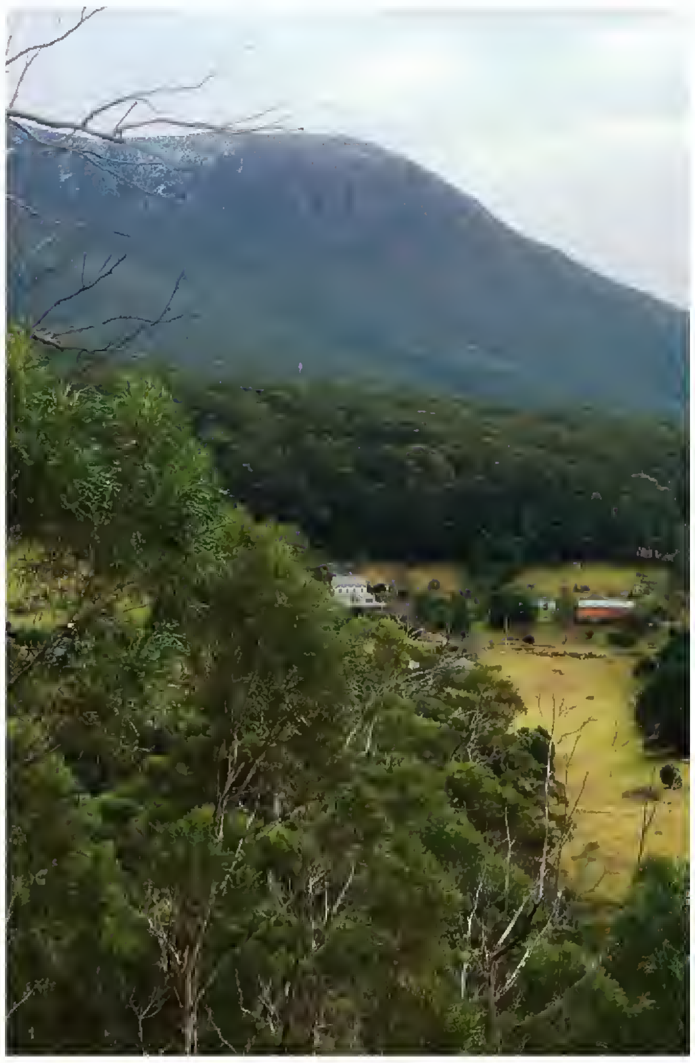


Fig. 43. The Organ Pipes, Mount Wellington (July 2015), the same view as depicted by Marianne North in painting no. *733*.

On 8 February, North travelled south to arrive at Geeveston, where she commented that the forest was gradually being destroyed by timber cutting and the construction of tramways penetrating deep in the forest. North returned to Ferntree where she rested for one week and wrote that 'they took me for a ride the next day up the steep hills; then we tied the horses to a fence and walked four miles up a still more beautiful tram-road, and among bigger trees than those at the Geeves. We measured one tree in that valley seventy-six feet round at a yard above the ground, and we heard of a perfect monster we did not see… the finest tree-ferns I had seen in Tasmania grew there; many of them were hung with clematis [*Clematis* spp.], like the English one' **[painting 725]**.[125] This painting is a view from Huon Road near Ferntree, looking south to North West Bay down the Browns River Valley.[126] North stayed at Red House, a boarding house situated on Huon Road opposite Chimney Pot Hill Road at Halls Saddle.[127] This was North's last painting to be completed in Australia. On 18 February, North departed Hobart on *S.S. Tararua*, destined for Bluff, New Zealand.[128]

Summary

Many of North's depictions of Australian landscapes present an unromantic representation of the harsh climatic conditions that some parts of Australia were experiencing in the late 1880s, with drought in parts of eastern Australia and seasonal bush-fires. She made a number of references to the effects of drought on vegetation and livestock in her writing and included active bush-fires in two paintings.

In contrast to her paintings of landscapes and 'plant portraits', her series of still lifes of groups of flowers and fruits are among the most proficient and 'painterly' of her Australian works. North provided no clear explanation of how she approached these paintings or the logistics of collecting and keeping the flower specimens fresh but it can be assumed that each still life was executed over a number of days when she was not travelling. She noted the abundance of flowers that were available at certain locations. For example, at Faulconbridge in the Blue Mountains she collected 25 species at a single location and completed another of Victorian and New South Wales flowers depicting nine species. In Western Australia she completed five still-life paintings, depicting a total of about 45 species and at Albany wrote that she was able to collect 25 species within hand-reach at a single location. Other still lifes of flowers and fruit included two paintings that she completed in Tasmania, one depicting 23 species from Mt Wellington and the other of eight fruiting Tasmanian shrubs.

With regard to the overall numbers of plants and flowers located and painted, Western Australia was North's most productive area. There she completed 23 paintings and depicted about 90 plant species. The next most productive state was New South Wales where she completed 20 paintings and depicted about 70 species. Because of her forced pace of travel in New South Wales, that state correspondingly had the highest proportion of landscape sketches which were executed quickly as limited time permitted.

Although the ever-present eucalypts were sometimes maligned and noted as dull and uninteresting by colonial travellers in descriptions of the Australian vegetation, North's enthusiasm for the great variety in the genus *Eucalyptus* and its relatives caused her to record their diversity and subtle differences. In a letter to Amelia Edwards she wrote 'I think I know a gum tree when I see it now! & they are wrongly called monotonous, for there are many varieties & the differences between them are very great - but they have one remarkable habit in common, they hate touching one another even with the ends of their knife like leaves - & every tree keeps apart from its neighbour even when their branches interlace across each other, the leaves of the different trees will be found clear of their neighbours'.[129] Of the Eucalypts, North depicted *Eucalyptus botryoides*, *E. camaldulensis*, *E. cordata*, *E. diversicolor*, *E. globulus*, *E. gomphocephala*, *E. macrocarpa*, *E. marginata*, *E. megacarpa*, *E. nicholii*, *E. pilularis*, *E. regnans* and *E. tetraptera*. In addition, she depicted other myrtaceous trees, including *Corymbia calophylla* and *C. ficifolia*, and *Angophora floribunda.*

North was undaunted at attempting to depict some of the more complex flowers and plants that she encountered. For example, she provided some exceptional paintings of a number of *Banksia* species. This genus was generally avoided by botanical artists of the era, apparently being unnerved by the complexity of the flower spikes (Collins et al. 2008). The species she depicted included *Banksia attenuata, B. coccinea*, *B. grandis*, *B. ilicifolia*, *B. littoralis* and *B. marginata*.

---

[125] *Recollections*. vol. 2, pp 174–175; www.kew.org/mng/gallery/725.html.

[126] Personal communication, Axel von Krusenstierna.

[127] Personal communication, Irene Schaffer.

[128] *Mercury* (Hobart), 19 Feb. 1881, p. 2, 'Cleared out.- February 18'.

[129] M. North to A. Edwards, 15 Sept. 1880. ABE 254, Somerville College Library, Oxford University.

Species in the ubiquitous Proteaceae she depicted mostly as feature plants included *Adenanthos cuneatus*, *Bellendena montana*, *Conospermum triplinervium*, *Grevillea banksia*, *G. bipinnatifida*, *G. buxifolia*, *G. leucopteris*, *G. wilsonii*, *Hakea cucullata*, *H. cyclocarpa*, *H. nitida*, *Isopogon anemonifolius*, *Macadamia integrifolia*, *Lambertia echinata*, *L. formosa*, *L. inermis*, *Persoonia graminea*, *Petrophile diversifolia*, *Synaphea polymorpha*, *Telopea speciosissima*, *Xylomelum occidentale* and *X. pyriforme*.

Another characteristic Australian genus that she depicted a number of species was *Acacia*, including *A. acuminata*, *A. alata*, *A. cyclops*, *A. dealbata*, *A. elongata*, *A. leucoclada* subsp. *argentifolia* and *A. paradoxa*.

In correspondence to Amelia Edwards, North provided a summary of some of the more characteristics species to be found in moist forest habitats of Victoria and Tasmania: 'I also had been to stay a week under the big trees of Fernshaw 60 miles from Melbourne - but as far as I can see, they are no rivals to those of America - except in height - which they do not show - & no painting can give them the look of height, if one does not see it in the originals! - You are quite right the trees of Australia generally having their leaves with the knife edge towards the light - so that at noon day the shade is smaller than ours but there is plenty of it in the evening & morning - but it is very wrong to talk of their monotonous grey colour - the variety of tints in the Australian landscapes are very remarkable & there are endless differences even amongst the gums alone. The dark blue green of what they call the Beech, & the bright yellow green of the Sassafras & celery topped pine, makes fine contrasts in all the gullies of Mt Wellington & the tree ferns are very fine - also a small plant they call true grass tree, resembling the pandanus in miniature is very elegant - the flowers are over, but I hope to find one sufficiently out to paint it but as I have seen no good painting of it'.[130]

North provided a number of observations concerning the Indigenous peoples as she travelled in Australia. Although most were brief observations and seemingly off-handed comments, they belie the then widely-held belief that Indigenous people were the lingering remnants of a vanishing peoples and were destined to be inexorably 'consumed' by European culture, dispossessed of their land and ultimately rendered extinct as a race. In contrast, North noted the 'wisdom' they exhibited in regard to bush-fires and their knowledge of the 'bush'.

North's time in Australia was increasingly accentuated by periods of illness mainly as a result of rheumatism and gumboils that were exacerbated by cold weather. She appears to have been slowly succumbing to an increasing exhaustion and lethargy during the later stages of her travels. Her opinion of Australia was positive and she had an irrepressible enthusiasm for the newness of the scenery and its plants. In a letter to Amelia Edwards, she wrote that 'there is a great charm to me in the newness of every tree & flower here - in spite of English names - & grass & clover & sheep & thistles &c &c.'[131]

North arrived back in England from Australia in early June 1881 to find her gallery completed and ready for the instalment of her paintings. It took another 12 months to finalise and mount the first exhibition which featured all the works that had been completed up to that time, including those that she did in Australia. A critique of the exhibition noted some of her Australian paintings as deserving of special attention, including those of *Nuytsia floribunda*, *Kennedia nigricans*, *Santalum acuminatum*, *Amyema miquelii* and *Telopea speciosissima* (Anon. 1882). The gallery catalogues (to run into six editions) were originally compiled by the Kew botanist William Botting Hemsley and later editions adapted from the earlier editions. In them Hemsley provided a systematic list of all the plants depicted in her paintings. The catalogues, because of their botanical relevance to the places she visited, were distributed to people and organisations outside of England. Ferdinand Mueller, in a letter to Hemsley, wrote that he had 'received the excellent publication, elaborated by you in elucidation of Miss North's paintings. This descriptive index must still more heighten the value of the superb collection, prepared under so much toil and at so great an expenditure by that gifted and generous Lady. Will you kindly present my compliments to her and say that I with great pleasure remember her visit and often think of her beautiful pictures'.[132]

Soon after returning to England from her Australian travels, North took some of her paintings to Charles Darwin at his home in Kent. Darwin later responded in writing and noted: '2d August 1881. I am so glad that I have seen your Australian pictures, and it was extremely kind of you to bring them here. To the present time I am often able to call up with considerable vividness scenes in various countries which I have seen, and it is no small pleasure; but my mind in this respect must be a mere barren waste compared with your mind.—I remain, dear Miss North, yours, truly obliged, Charles Darwin' (North 1893a).

In the years following her Australian visit, North travelled to South Africa (1882), Seychelles (1883) and Chile (1884) where she completed many more paintings. She spent 1885 organising the paintings in her gallery, which had been extended to accommodate the additional paintings, and of which her personal arrangement persists until the present day. In 1886 she retired to a property at Alderley, Gloucestershire, where she remained in persistent ill-health until her death in 1890.

---

[130] M. North to A. Edwards, 7 Feb. 1881. ABE 255, Somerville College Library, Oxford University.

[131] M. North to A. Edwards, 15 Sept. 1880. ABE 254, Somerville College Library, Oxford University.

[132] F. Mueller to W. Hemsley, 24 July 1882. Correspondence of Ferdinand von Mueller, Royal Botanic Gardens Victoria.

Conclusion

North's contribution to Australian botany and ecology has been generally overlooked by many taxonomists and art historians because of the inability to classify her work as either art or science. She did not 'discover' any new species or systematically collect herbarium specimens in Australia. Only a single specimen collected by her of any Australian plant is extant as a herbarium specimen; a collection of the flowers of *Eucalyptus macrocarpa* which was insistently appropriated by Ferdinand Mueller for the Melbourne Herbarium. Despite some suggestions by researchers that she had collected herbarium specimens for Kew during her world travels, there is only scant evidence of this, and only a small number of specimens have been located there.

By associating North's paintings with the relevant text in her writing, her works offer insights into the Australian environment and the existing attitudes in colonial Australia. By the time that North visited Australia in 1880, there was an increasing awareness of the loss of the natural environment (Mueller 1870, 1871, 1890; Dixon 1892; Tyrrell 1999; Douglas 2014). Her paintings present an unromantic depiction of the environment showing the often harsh climatic conditions of the time, and an understanding of fire, drought, and the interactions and evolutionary implications between vegetation, the environment and animals.

Acknowledgements

I would like to thank Julia Buckley and Eleanor Hasler for facilitation of images of Marianne North's paintings at Royal Botanic Gardens Kew. Kate O'Donnell of Somerville College Library, Oxford University, provided copies of letters from Marianne North to Amelia Edwards. Claire Burton, Cairns Regional Council, prepared the maps. John and Sandy Learmont provided guidance and hospitality at the Bunya Mountains. Historical information was provided by Jean Town, Dalby Family History Association, and Mary Mannings, Warwick Historical Society. Paul Forster (BRI) provided information of plant distribution in the Bunya Mts. Information on Camden was generously provided by John Wrigley and Pauline Downing. Leon Fuller provided guidance and hospitality at Illawarra, and historical information was provided by Michael Organ and Joseph Davis. Mel Flyte provided information about Elizabeth Bay House. Richard Morony provided information about Faulconbridge, and R. J. Turner and Merle Thompson provided identification of Blue Mountains plants. Robert Blackburn provided information on Marianne North's visit to Elizabeth Bay House. Sandra Lanteri, Brighton Historical Society, provided information about the location of Marianne North's Brighton painting. Anne Brake and Pam Harris, Fremantle Historical Society, provided information about Marianne North's painting locations. Neil and Ann Pettit provided information and photos of Albany. Alex George and Ellen J. Hickman provided identification of Western Australian plants. For historical information and location of Marianne North's paintings in Tasmania, I thank Margaret Davies, Louise Rainbow, Irene Schaffer and Axel von Krusenstierna. Elaine Walker, provided historical information on Quamby Bluff and the Reverend John Evans. Christine and Sib Corbett assisted with identification of Tasmanian plants. Haidi Beard facilitated access to archival materials at James Cook University Library. An anonymous reviewer provided perceptive comments and suggestions for improvement to the manuscript.

References

Agnew, E. (2011). 'An old vagabond': Science and sexuality in Marianne North's representations of India. *Nineteenth-Century Gender Studies* 7.2. www.ncgsjournal.com/issue72.

ALA (2019). *Atlas of Living Australia*, http://www.ala.org.au. Accessed May 2019.

Anderson, M. (2003). A monumental autobiography: Marianne North's Gallery at Kew Gardens. *Limina: A Journal of Historical and Cultural Studies* 9: 59–77.

Anon. (1882). The Marianne North Gallery at Kew. *Gardeners' Chronicle* new series, vol. 17, no. 441, 10 June 1882: 763–764, fig. 117.

Anon. (1883). [Untitled]. *Gardeners' Chronicle* new series, vol. 20, no. 514, 3 November 1883: 564.

Anon. (1890). Miss Marianne North. *Gardeners' Chronicle* 3rd series, vol. 8, no. 193, 6 September 1890: 275.

Anon. (1914). *Official Guide to the North Gallery*, 6th Edition. Royal Gardens, Kew, London.

APC (2019). *Australian Plant Census*, IBIS database, Centre for Australian National Biodiversity Research, Council of Heads of Australasian Herbaria, http://www.chah.gov.au/apc/index.html. Accessed May 2019.

APNI (2019). *Australian Plant Name Index*, IBIS database, Centre for Australian National Biodiversity Research, Australian Government, Canberra, http://www.cpbr.gov.au/cgi-bin/apni, accessed May 2019.

Baker, J. G. (1882). Miss North's Crinums. *Gardeners' Chronicle* new series, vol. 17, no. 438, 20 May 1882: 671.

Baker, J. G. (1889). New petaloid Monocotyledons from Cape Colony. *Journal of Botany, British and Foreign* 27: 42–45.

Baker, J. G. (1891). *Gardeners' Chronicle* 3rd series, July 18, 1891, p. 66.

Baker, J. G. (1895). *Kniphofia northiae*. *Curtis's Botanical Magazine*, 3rd series, vol. 51: t. 7412.

Blunt, W. & Stearn, W. T. (1971). *The Art of Botanical Illustration*. Collins, London.

Brooke, M. (1913). *My Life in Sarawak by the Ranee of Sarawak*. Methuen & Co. Ltd, London.

Bywater, J. (1980). *Rainforests of the Illawarra*. Wollongong Studies in Geography 3. University of Wollongong, Wollongong.

Cadwallader, P. L. (1996). *Overview of the Impacts of Introduced Salmonids on Australian Native Fauna*. Australian Nature Conservation Agency, Canberra.

Carroll, K. von Zinnenburg (2018). NonWest by North. *Third Text* 32(2–3): 290–310. DOI: 10.1080/09528822.2018.1461824.

Collins. K., Collins, C. & George, A. S. (2008). *Banksias*. Bloomings Books, Melbourne.

Davis, J. (2017). *"I wished I were an Osborne": The Botanical Artist Marianne North at Doondale in Illawarra*. https://www.academia.edu/33427719/.

Dixon, S. (1892). The effects of settlement and pastoral occupation in Australia upon the indigenous vegetation. *Transactions and Proceedings and Report of the Royal Society of South Australia* 15: 195–206.

Douglas, K. (2014). "For the sake of a little grass": a comparative history of settler science and environmental limits in South Australia and the Great Plains. In, J. Beattie *et al.* (eds), *Climate, Science, and Colonization*, pp. 99–117. Palgrave Macmillan, New York.

Dowe, J. L. (2016a). Walter Hill: his involvement with palms (Arecaceae), and notes on his herbarium and expeditions of 1862 and 1873. *Austrobaileya* 9(4): 489–507.

Dowe, J. L. (2016b). Walter Hill's palm collection at the Brisbane Botanic Gardens, 1855–1881. *Palms & Cycads* 130: 11–24.

Dowe, J. L. (2018). Marianne North's paintings of Australian gardens, 1880–81. *Australian Garden History* 30(1): 12–15.

Fallding, H. & Benson, J. S. (1985). Natural vegetation and settlement at Macquarie Pass, Illawarra region, New South Wales. *Cunninghamia* 1(3): 285–311.

Gardiner-Garden, C. W. (1953). History of the Village of Figtree. *Illawarra Historical Society Bulletin* September 1953: 248–249.

George, A. S. (2009). *Australian Botanist's Companion*. Four Gables Press, Kardinya.

Gladston, L. H. (2012). *The Hybrid Work of Marianne North in the Context of Nineteenth-century Visual Practices*. PhD Thesis, University of Nottingham. http://eprints.nottingham.ac.uk/12653/1/Lynne_Gladston_thesis.pdf, accessed May-June 2017.

Goyder, D., Griggs, P., Nesbitt, M., Parker, L. & Ross-Jones, K. (2012). Sir Joseph Hooker's collections at the Royal Botanic Gardens, Kew. *Curtis's Botanical Magazine* 29(1): 66–85.

Griffith, J. (2015). *A History of the Osbornes of Kangaroo Valley, Australia*. Kangaroo Valley Historical Society.

Guelke, J. K. & Morin, K. M. (2001). Gender, nature, empire: women naturalists in nineteenth century British travel literature. *Transactions of the Institute of British Geographers* 26: 306–326.

Haller, E. (2009). The botanical works of Marianne North (painter, writer, and traveller) edited by absorption into Virginia Woolf's writing. In, E. McNees & S. Veglahn (eds), *Woolf Editing/Editing Woolf: Selected Papers from the Eighteenth Annual Conference on Virginia Woolf*, pp. 174–181. Clemson University Digital Press, Clemson.

Hazzard, M. (1984). *Australia's Brilliant Daughter*. Greenhouse Publications, Richmond.

Hemsley, W. B. (1881). The "North" Gallery, Kew. *Gardeners' Chronicle*, new series, vol. 16, no. 414: 724, fig. 146.

Hemsley, W. B. (1882). *The Gallery of Marianne North's Paintings of Plants and Their Homes, Royal Gardens Kew: Descriptive Catalogue*. 1st Edition. Spottiswoode & Co., London.

Hemsley, W. B. (1885). The Marianne North Gallery at Kew. *Gardeners' Chronicle*, new series, vol. 24, no. 610, 5 September 1885: 296.

Hemsley, W. B. (1886). *The Gallery of Marianne North's Paintings of Plants and Their Homes, Royal Gardens, Kew. Descriptive Catalogue*. 4th Edition. Eyre & Spottiswoode, London.

Hill, W. (1875). *Catalogue of the Plants in the Queensland Botanic Gardens*. J.C. Beal, Brisbane.

Hooker, J. D. (1881). *Nepenthes northiana*, sp. nov. *Gardeners' Chronicle*, new series, vol. 16, no. 414, 3 December 1881: 717, f. 144, Suppl. Sheet, unnumbered.

Hooker, J. D. (1884). *Northea seychellana*. *Hooker's Icones Plantarum* 15(4): 57–58, Plate 1473 [as *Northia seychellana*].

Hopper, S. D. & Lambers, H. (2009). Darwin as a plant scientist: a Southern Hemisphere perspective. *Trends in Plant Science* 14(8): 421–435.

Humphreys, R. (2017). *Bonyi-Bonyi: Life and Legends of the Bunya Mountains*. Bunya Mountains Natural History Association, Dalby.

Kerrigan, P. (2010). Marianne North: painting a Darwinian vision. *Visual Culture in Britain* 11(1): 1–24.

Losano, A. (1997). A preference for vegetables: the travel writings and botanical art of Marianne North. *Women's Studies* 26(5): 423–448.

Mace, B. (1996). Mueller - champion of Victoria's giant trees. *Victorian Naturalist* 113(4): 198–207.

Maroske, S. (2014). 'A taste for botanic science': Ferdinand Mueller's female collectors and the history of Australian botany. *Muelleria* 32: 72–91.

Middleton, D. (1965). *Victorian Lady Travellers*. Routledge & Kegan Paul, London.

Millard, T., Le Cornu, E., Smith, R., Hasler, E., Cowdy, H., Chisholm, R. & King, E. (2011). The conservation of 830 oil paintings by Marianne North. *Journal of the Institute of Conservation* 34(2): 159–172.

Moon, B. E. (1980). Biographical note. In, A. Huxley (ed.), *A Vision of Eden; The Life and Work of Marianne North*, pp. 234–237. Royal Botanic Gardens Kew, Surrey.

Moravek, S., Luly, J., Grindrod, J. & Fairfax, R. (2013). The origin of grassy balds in the Bunya Mountains, southeastern Queensland, Australia. *The Holocene* 23(2): 305–315.

Mueller, F. (1870). *On the Application of Phytology to the Industrial Purposes of Life*. Mason, Firth, and M'Cutcheon, Melbourne.

Mueller, F. (1871). *Forest Culture in its Relation to Industrial Pursuits*. John Ferres, Melbourne.

Mueller, F. (1879–1884). *Eucalyptographia. A Descriptive Atlas of the Eucalypts of Australia and the Adjoining Islands*. John Ferres, Melbourne.

Mueller, F. (1890). Inaugural address by the president. In, W. Baldwin Spencer (ed.), *Report of the Second Meeting of the Australasian Association for the Advancement of Science held at Melbourne, Victoria, in January, 1890*, pp. 1–26. Published by the Association, Sydney.

North, M. (1892). *Recollections of a Happy Life being the Autobiography of Marianne North Edited by her Sister Mrs. John Addington Symonds*. 1st Edition, 2 vols. MacMillan & Co., London.

North, M. (1893a). *Recollections of a Happy Life being the Autobiography of Marianne North Edited by her Sister Mrs. John Addington Symonds*. 2nd Edition with corrections, 2 vols. MacMillan & Co., London.

North, M. (1893b). *Some Further Recollections of a Happy Life, Selected from the Journals of Marianne North Chiefly Between the Years 1859 and 1869 Edited by her Sister Mrs. John Addington Symonds*. MacMillan & Co., London.

O'Connor, M. (1997). Marianne North. In, B. Brothers & J.M. Gergits (eds), *British Travel Writers, 1876–1909*. Dictionary of Literary Biography Vol. 174, pp. 251–255. Gale Research, Detroit.

Olsen, P. (2013). *Collecting Ladies: Ferdinand von Mueller and Women Botanical Artists*. National Library of Australia, Canberra.

Payne, M. (2016). *Marianne North: A Very Intrepid Painter*. Royal Botanic Gardens Kew, Richmond.

Plug, C. (2014). *North, Miss Marianne (botanical artist)*. S2A3 Biographical Database of South African Science. www.s2a3.org.za, accessed 16 Aug. 2017.

Ponsonby, L. (2002). Marianne North in India. *SAALG Newsletter*. www.bl.uk/reshelp/bldept/apac/saalg/issue2.

Raby, P. (1996). *Bright Paradise: Victorian Scientific Travellers*. Princeton University Press, Princeton.

Ritchie, R. (1989). *Seeing the Rainforests in 19th-century Australia*. Rainforest Publishing, Sydney.

Rowan, E. (1905). An Australian artist's adventures. *New Idea Magazine*, 6 February 1905, p. 714.

Ryall, A. (2008). The world according to Marianne North, a nineteenth-century female Linnaean. *TijdSchrift voor Skandinavistiek* 29 (1 & 2): 195–218.

Sheffield, S. (2001). *Revealing Worlds: Three Victorian Women Naturalists*. Routledge, London.

Siqueira, V. B. (2015). Configuring Latin America: the views by Rugendas and Marianne North. *19&20, Rio de Janeiro* 10(2). http://www.dezenovevinte.net/uah2/vbs_en.htm.

Standish, A. (2008). *Australia Through Women's Eyes*. Australian Scholarly Publishing, North Melbourne.

Tyrrell, I. (1999). *True Gardens of the Gods: California-Australian Environmental Reform, 1860–1930*. University of California Press, Berkeley.

Vellacott, H. (ed.) (1986). *Some Recollections of a Happy Life: Marianne North in Australia and New Zealand.* Edward Arnold, Melbourne.

Watts, R. (2017). Science and public understanding: the role of the historian of education. *History of Education* 46(2): 147–161.

Whitefield, E. (1897). *History of the Parishes in the Northern Part of Diocese of Tasmania*. St John's Church, Launceston.

Manuscript accepted 13 January 2020

Appendix 1 Plants, birds, mammals, insects and reptiles depicted in Marianne North's Australian paintings of 1880-1881, as exhibited in the Marianne North Gallery, Royal Botanic Gardens Kew, U.K.*

Plant nomenclature follows the *Australian Plant Name Index*, IBIS database, Centre for Australian National Biodiversity Research, Australian Government, Canberra, http://www.cpbr.gov.au/cgi-bin/apni, and that of other organisms follows the *Atlas of Living Australia*, https://www.ala.org.au/.

*paintings prefixed with MNS are held in the Royal Botanic Gardens Kew Library, Art and Archives.

Species name	Painting number
PLANTS	
Acacia acuminata Benth.	751, 763
Acacia alata R.Br.	729
Acacia cyclops A.Cunn. ex G.Don.	753
Acacia dealbata Link	725
Acacia elongata Sieber ex DC.	785
Acacia leucoclada subsp. *argentifolia* Tindale	726
Acacia paradoxa DC.	778
Actinotus helianthi Labill.	759
Adenanthos cuneatus Labill.	729
Agonis flexuosa (Willd.) Sweet	757
Agrostocrinum scabrum (R.Br.) Baill.	750
Allocasuarina decussata (Benth.) L.A.S.Johnson	782
Alyogyne huegelii (Endl.) Fryxell	791
Amyema miquelii (Lehm. ex Miq.) Tiegh.	745
Amyema pendula (Seiber ex Spreng.) Tiegh.	748
Angophora floribunda (Sm.) Sweet	779
Anigozanthos flavidus Redouté	776
Anigozanthos gabrielae Domin	740
Anigozanthos humilis Lindl.	740
Anigozanthos manglesii D.Don	740
Anigozanthos manglesii x *A. humilis*	740
Anopterus glandulosus Labill.	730
Anthocercis viscosa R.Br.	750
Aralia sp.	783
Araucaria bidwillii Hook.	743, 763, 767, 768, 771, 773, 781
Araucaria cunninghamii Mudie var. *cunninghamii*	738
Araucaria heterophylla (Salisb.) Franco	749
Archontophoenix alexandrae (F.Muell) H.Wendl. & Drude	743
Archontophoenix cunninghamiana (H.Wendl.) H.Wendl. & Drude	743, 760, 781
Arctotheca calendula (L.) Levyns	742
Areca northiana W.Hill ex Hemsl.	743
Aristotelia peduncularis (Labill.) Hook.f.	711
Asplenium australasicum (J.Sm.) Hook.	732, 767
Astroloma pallidum R.Br.	740
Atherosperma moschatum Labill. subsp. *moschatum*	711, 725
Atriplex isatidea Moq.	729
Bambusa sp.	732
Banksia attenuata R.Br.	775
Banksia coccinea R.Br.	722
Banksia grandis Willd.	741, 764, 780
Banksia ilicifolia R.Br.	764
Banksia littoralis R.Br.	756
Banksia marginata Cav.	MNS48
Bauera rubioides Andrews	759
Beaufortia decussata R.Br.	729
Bellendena montana R.Br.	730

Species name	**Painting number**
Billardiera heterophylla (Lindl.) L.Cayzer & Crisp	750
Billardiera longiflora Labill.	711, 730
Boronia floribunda Sieber ex Rchb.	759
Brachychiton populneus (Schott & Endl.) R.Br. subsp. *populneus*	779
Brachychiton rupestris (T.Mitch. ex Lindl.) K.Schum.	736
Bursaria spinosa Cav.	MNS54
Byblis gigantea Lindl.	755
Callistemon citrinus (Curtis) Skeels	749
Callistemon salignus (Sm.) Colvill ex Sweet	716
Callitris rhomboidea R.Br. ex Rich.& A.Rich.	709
Callitris sp.	737
Caryota urens L.	732
Casuarina cunninghamiana Miq. subsp. *cunninghamiana*	728, 770, 792
Cephalotus follicularis Labill.	744
Comesperma ericinum DC.	759
Conospermum triplinervium R.Br.	740
Conostylis aculeata R.Br.	744
Coprosma hirtella Labill.	711
Cordyline australis (G.Forst.) Endl.	709, 754
Cordyline petiolaris (Domin) Pedley	763, 767
Corymbia calophylla (Lindl.) K.D.Hill & L.A.S.Johnson	757
Corymbia ficifolia (F.Muell.) K.D.Hill & L.A.S.Johnson)	789
Cosmelia rubra R.Br.	750
Cyathea australis (R.Br.) Domin	732
Cyathodes glauca Labill.	730
Dampiera linearis R.Br.	744
Dampiera stricta (Sm.) R.Br.	759
Dasypogon bromeliifolius R.Br.	750
Dasypogon hookeri J.Drumm.	756
Daviesia ulicifolia Andrews	759
Dendrocnide moroides (Wedd.) Chew	781
Dicksonia antarctica Labill.	715, 747, 758, 774, 777, 784
Diuris punctata Sm.	759
Diuris sp.	742
Doryanthes palmeri W.Hill ex Benth.	778, 844
Doryphora sassafras Endl.	711, 715
Drosera macrantha Endl.	744
Drosera menziesii R.Br. ex DC.	744
Drymophila cyanocarpa R.Br.	730
Dypsis lutescens (H.Wendl.) Beentje & J.Dransf.	732
Epacris longiflora Cav.	742, 759
Epacris purpurascens Banks ex Sims var. *purpurascens*	759
Eucalyptus botryoides Sm.	760
Eucalyptus camaldulensis Dehnh.	792
Eucalyptus cordata Labill.	730
Eucalyptus diversicolor F.Muell.	782
Eucalyptus globulus Labill.	720, 725
Eucalyptus gomphocephala DC.	780
Eucalyptus macrocarpa Hook.	751
Eucalyptus marginata Donn ex Sm.	741, 762
Eucalyptus megacarpa F.Muell.	741
Eucalyptus nicholii Maiden & Blakely	770
Eucalyptus pilularis Sm.	760
Eucalyptus regnans F.Muell.	746, 747, 758, 777
Eucalyptus tetraptera Turcz.	791

Species name	**Painting number**
Euphrasia collina R.Br.	730
Exocarpos cupressiformis Labill.	730
Ficus macrophylla Desf. ex Pers.	788
Ficus watkinsiana F.M.Bailey	781
Gaultheria hispida R.Br.	711
Gompholobium confertum (DC.) Crisp	750
Gompholobium grandiflorum Sm.	759
Gompholobium polymorphum R.Br	722
Goodenia coerulea R.Br.	744
Grevillea banksii R.Br.	762
Grevillea bipinnatifida R.Br.	755
Grevillea buxifolia (Sm.) R.Br.	759
Grevillea leucopteris Meisn.	780
Grevillea wilsonii A.Cunn.	755
Hakea cucullata R.Br.	791
Hakea cyclocarpa Lindl.	791
Hakea nitida R.Br.	729
Helichrysum sp.	759
Isopogon anemonifolius (Salisb.) Knight	759
Isotoma hypocrateriformis (R.Br.) Druce	750, 755
Johnsonia lupulina R.Br.	750
Jubaea chilensis (Molina) Baill.	603
Kennedia coccinea (Curtis) Vent.	750
Kennedia nigricans Lindl.	766
Kennedia rubicunda (Schneev.) Vent.	759
Kingia australis R.Br.	741
Lambertia echinata R.Br.	729
Lambertia formosa Sm.	759
Lambertia inermis R.Br. var. *inermis*	729
Leptecophylla juniperina (J.R.Forst.) & G.Forst.) C.M.Weiller	730
Leptospermum laevigatum (Gaertn.) F.Muell.	752
Leptospermum myrsinoides Schltdl.	752
Leucopogon verticillatus R.Br.	757, 782
Linospadix monostachyus (Mart.) H.Wendl.	732
Livistona australis (R.Br.) Mart.	727, 760
Lomandra sp.	716, 792
Loranthaceae sp.	726
Macadamia integrifolia Maiden & Betche	790
Macropidia fuliginosa (Hook.) Druce	740
Macrozamia communis L.A.S.Johnson	719
Macrozamia fraseri Miq.	756
Macrozamia riedlei (Fisch. ex Gaudich.) C.A.Gardner	741, 782
Marianthus candidus Hügel ex Endl.	729
Melaleuca glauca (Sweet) Craven	776
Melaleuca huegelii Endl.	753
Mirbelia dilatata R.Br. ex Dryand.	750
Nothofagus cunninghamii (Hook.) Oerst.	715, 761, 777
Nuytsia floribunda (Labill.) R.Br. ex G.Don	764, 766
Nymphaea gigantea Hook.	783
Nymphaea sp.	732
Olearia argophylla (Labill.) F.Muell. ex Benth.	761
Ozothamnus ledifolius (A.Cunn. ex DC.) Hook.f.	730
Pandanus sp.	783
Pandorea pandorana (Andrews) Steenis	746, 749, 760
Passiflora sp.	738

Species name	Painting number
Patersonia glabrata R.Br.	759
Persoonia graminea R.Br.	744
Petrophile diversifolia R.Br.	750
Philotheca myoporoides (DC.) Bayly	759
Philotheca salsolifolia (Sm.) Druce	759
Phragmites australis (Cav.) Trin. ex Steud.	768
Phyllocladus aspleniifolius (Labill.) Hook.f.	725, 730
Pimelea linifolia Sm.	759
Pimelea nivea Labill.	730
Pimelea rosea R.Br.	750
Platycerium superbum de Jonch. & Hennipman	732
Platylobium triangulare R.Br.	742
Poa labillardierei Steud.	763, 768, 773
Prostanthera lasianthos Labill.	730
Prunus persica (L.) Batsch.	603
Ptilotus manglesii (Lindl.) F.Muell.	755
Pultenaea canescens A.Cunn.	759
Rhodanthe rubella (A.Gray) Paul G.Wilson	755
Richea dracophylla R.Br.	711, 715
Roystonea regia (Kunth) O.F.Cook	732
Santalum acuminatum (R.Br.) A.DC.	745, 765
Siloxerus filifolius (Benth.) Ostenf.	744
Stylidium graminifolium Sw.	759
Styphelia stomarrhena (Sond.) Sleumer	740
Styphelia tubiflora Sm.	759
Synaphea polymorpha R.Br.	750
Syncarpia glomulifera (Sm.) Nied.	710
Tasmannia lanceolata (Poir.) A.C.Sm.	730
Telopea speciosissima (Sm.) R.Br.	785
Telopea truncata (Labill.) R.Br.	730
Tetratheca affinis Endl.	750
Tetratheca ciliata Lindl.	759
Thelymitra sp. (1)	742
*Thelymitr*a sp. (2)	742
Thelymitra crinita Lindl.	750
Thysanotus sp.	750
Trochocarpa thymifolia (R.Br.) Spreng.	730
Woollsia pungens (Cav.) F.Muell.	759
Xanthorrhoea gracilis Endl.	756
Xanthorrhoea johnsonii A.T.Lee	737
Xanthorrhoea preissii Endl.	741, 756, 764
Xanthosia rotundifolia DC.	750
Xylomelum occidentale R.Br.	735
Xylomelum pyriforme (Gaertn.) Knight	739
BIRDS	
Acanthorhynchus superciliosus (Gould, 1837) (Western spinebill)	789
Alectura lathami [J.E.Gray, 1831] (Brush turkey)	781
Grus(Mathewsia) rubicunda [Perry, 1810] (Brolga)	728
Cacatua roseicapilla (Vieillot, 1817] (Galah)	762
Calyptorhynchus (Zanda) funereus (Shaw, 1794) (Yellow-tailed black cockatoo)	790
Dromaius novaehollandiae (Latham, 1790) (Emu)	782
Stagonopleura (Zonaeginthus) bella (Latham, 1801) (Beautiful firetail)	720
Malurus splendens (Quoy & Gaimard, 1830) (Splendid wren)	745
Menura novaehollandiae (Latham, 1801) (Lyrebird)	747
Platycercus elegans (Gmelin, 1788) (Crimson rosella)	770

Species name	**Painting number**
Psophodes olivaceus [Latham, 1801] (Eastern whipbird)	771
Sericornis citreogularis (Gould, 1838) (Yellow-throated scrubwren) (nest only)	771
MAMMALS	
Aepyprymnus rufescens (Gray, 1837) (Rufous bettong)	710
Cercartetus concinnus (Gould, 1845) (Western pygmy possum)	765
Macropus sp. (Wallaby)	758, 773
Petaurus breviceps (Waterhouse, 1839) (Sugar glider)	746
Phascolarctos cinereus (Goldfuss, 1817) (Koala)	735, 792
Trichosurus vulpecula (Kerr, 1792) (Common brushtail possum: male)	748
Ornithorhynchus anatinus (Shaw, 1799) (Platypus)	792
INSECTS	
Metura elongatus (Saunders, 1847) (Casemoth)	752
REPTILES	
Moloch horridus (Gray, 1841) (Thorny devil)	755

Date of Publication:
April 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

A Systematic Flora Survey, Floristic Classification and High-Resolution Vegetation Map of Lord Howe Island

Paul Sheringham [1], Peter Richards[2], Phil Gilmour[3], Jill Smith[1] and Ernst Kemmerer [4]*

[1] Department of Planning, Industry and Environment, Locked Bag 914 COFFS HARBOUR NSW 2450
[2] 17 Coronation Avenue, SAWTELL NSW 2452
[3] 523 Roses Rd, GLENIFFER, NSW 2454
[4] Cradle Coast NRM, PO Box 338, BURNIE TAS 7320
* Author for correspondence: paul.sheringham@environment.nsw.gov.au

***Abstract*:** The present study took advantage of the availability of high resolution ADS40 digital imagery to 1) systematically resample the vegetation of the Lord Howe Island Group (LHIG, excluding Ball's Pyramid); 2) conduct a numerical analysis of the floristic data; 3) map vegetation extent and the distribution of vegetation communities and 4) compare the resultant classification and mapping with those of Pickard (1983). In July 2013, a total of 86 full floristic and 105 rapid floristic sites were sampled across the island, based on a stratified random sampling design. A hierarchical agglomerative clustering strategy (Flexible UPGMA) and Bray-Curtis dissimilarity coefficient with default beta, along with nearest neighbour analysis to identify anomalous site allocations, was used to analyze the floristic data. In total 33 vegetation communities were delineated and mapped: 19 mapping units from the full floristic analysis; 7 variants identified within five of the above 19 groups; 3 mapping units from analysis of canopy-only floristic data; and 4 mapping units recognised in previous studies that are mapped but were not sampled in this survey. The resultant list of vegetation communities and non-vegetation mapping units, along with their equivalence to Pickard (1983) and DECC (2007) units, is provided.

222 plant taxa were recorded in the survey, including 47 exotic taxa. Weeds are a common component of some communities, particularly coastal strandline communities, the shrublands of the southern mountains and regenerating vegetation on landslips. The threatened plants *Xylosma parvifolia*, *Lepidorrhachis mooreana,* and *Geniostoma huttonii* were recorded in floristic sites. Two communities, Gnarled Mossy Cloud Forest and Lagunaria Swamp Forest are listed as Critically Endangered Ecological Communities under the NSW *Biodiversity Conservation Act 2016* (BC Act). Coastal Saltmarsh, an Endangered Ecological Community listed under the BC Act, also occurs on the main island. An assessment of the conservation status of the vegetation communities recognised in the present study is provided. A number of communities warrant further consideration for listing as threatened ecological communities.

Significant improvement in vegetation community attribution and spatial resolution was possible with the high-resolution digital imagery, however Pickard's 1983 classification and mapping was found to be a comprehensive and accurate description of the island's vegetation considering the imagery available at the time.

This project has resulted in greatly improved accuracy of vegetation mapping linework for the LHIG. The Pickard (1983) vegetation map comprised 321 individual polygons, whereas the new map includes 1 840 polygons of sufficient accuracy to support detailed environmental planning programs, particularly within the Settlement area where spatial accuracy in the delineation of native vegetation is critical. The new vegetation communities were applied to the updated linework to complete the project. Detailed profiles were compiled of each vegetation community for which enough information was available. These profiles should prove useful in field identification of vegetation types and the assessment of their conservation status.

***Cunninghamia* (2020) 20: 035–098**
doi:10.7751/cunninghamia.2020.20.002

© 2020 Royal Botanic Gardens and Domain Trust

Introduction

The oceanic Islands of Australia and the Pacific Ocean have unique assemblages of flora and fauna that reflect their long history of evolution in isolation. The Lord Howe Island Group (LHIG) is no exception, with nearly half of the native plant species of the Group found nowhere else in the world (Green 1994; DECC 2007; Hutton 2010a, 2010b).

The first vegetation classification and mapping for the LHIG was prepared by Pickard (1974, 1983), utilising black-and-white aerial photography, a decade undertaking numerous meandering traverses across the island on foot and by boat, and 73 floristic-site surveys (Pickard 1974, 1983; Clarke 1974). The aerial photography used was captured in April 1966 at scales of 1:18 700 and 1:21 400. A digital version of Pickard's map was created for operational purposes by the New South Wales (NSW) Department of Environment and Conservation in the 1990s, and this was later revised by Hunter (Hunter 2002; Hunter and Hodgson 2005). The main limitation of the Pickard vegetation mapping is that positional accuracy is not sufficient to effectively manage vegetation and environmental planning issues on the island, especially within the Settlement, an area of approximately 160 ha consisting of those parts of the main island outside of the Permanent Park Preserve (PPP; see Study Area below), and which supports human habitation and infrastructure as well as a mixture of cleared and vegetated land. Accurate vegetation mapping is a vital management and conservation tool, as it supports a variety of environmental planning processes, particularly as legislation becomes more specific regarding the definition of threatened ecological communities.

In 2012, high-resolution digital aerial imagery of the LHIG was captured by NSW Land and Property Information (LPI; http://www.lpi.nsw.gov.au/ [verified 7 July 2016]) – the primary provider of land information services in NSW – at 10 cm resolution using a Leica Geosystems® Airborne Digital Sensor (ADS40 Digital Image Acquisition System). At that time, the NSW Office of Environment and Heritage (OEH) was engaged by the Lord Howe Island Board (LHIB) to undertake vegetation mapping for the Settlement area of Lord Howe Island (LHI) using the new imagery and applying the vegetation classification developed by Pickard (1983). The purpose of the Settlement mapping project was to upgrade the spatial accuracy of vegetation mapping so that it could be used operationally by the LHIB at a scale of 1:1 000.

Following the successful completion of the Settlement mapping project, the LHIB and OEH undertook to complete the vegetation mapping of the rest of the LHIG, although excluding Balls Pyramid. Furthermore, it was determined that this new mapping should be underpinned by a revised vegetation classification based on a stratified random sampling design for floristic survey to gather sufficient plot-based data for rigorous statistical analysis of the vegetation of the LHIG. The vegetation communities identified form the basis of a new and complete vegetation map of the LHIG (excluding Balls Pyramid). The communities identified in this study are compared with those described by Pickard (1983), and detailed profiles of each vegetation community have been prepared (See Appendix 1). The vegetation mapping, classification and accompanying profiles will support local environmental planning and provide baseline data that may be used to measure changes in floristic composition and structure over time.

Study Area

Many previous reports, including those of Recher and Clarke (1974), Pickard (1983), Green (1994), DECC (2007) and Hutton (2008), provide accounts of the geology, physiography, soils, climate, history of settlement, flora, fauna, and vegetation of the LHIG to varying levels of detail and comprehensiveness. A brief overview of the study area is provided here.

The LHIG is located 760 kilometres north-east of Sydney and 600 kilometres east of Port Macquarie. It consists of the main island and a number of smaller surrounding islands. The Group was first sighted by Henry Lidgbird Ball in 1788, aboard the HMS Supply. It was first settled in 1834. Most of the LHIG (about 75%) is now protected within the Lord Howe Island Permanent Park Preserve (PPP). The PPP was created in January 1982 with the purpose of preserving native flora and fauna in accordance with the *Lord Howe Island Act 1953* (NSW) and the *National Parks and Wildlife Act 1974* (NSW). It is managed by the LHIB.

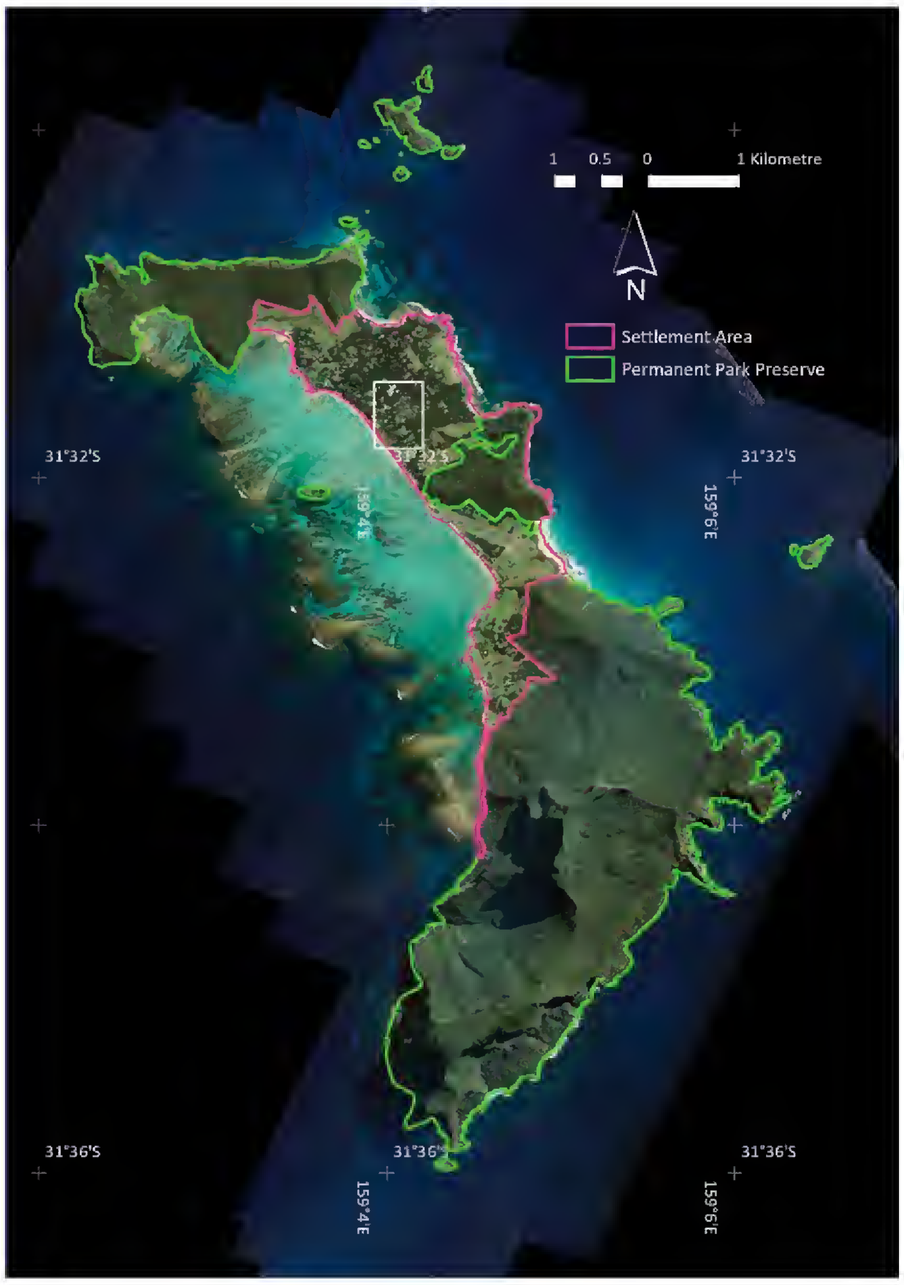


Fig. 1. Lord Howe Island Group (excluding Balls Pyramid), showing location of the Settlement Area and the Permanent Park Preserve. The white rectangle denotes the location of Figure 5.

Climate

The LHIG has wet and cool winters, with a mean daily maximum temperature of 18.9 C and minimum of 13.5 C. Summers are drier, and mild to warm, with a mean daily maximum of 25.7 C and a minimum of 19.2 C. Average annual rainfall is 1510 mm (Bureau of Meteorology 2015), however annual rainfall has been declining in recent decades (Auld & Leishman 2015). Pickard (1983) cites LHIG mean annual rainfall of 1676 mm, based upon data from the years 1886 to 1967. Temperatures on the high plateau of Mt Gower (875 m above sea level [asl]) are 6–8 C cooler than at sea level (LHIB 2002). The rainfall in the mountainous southern half of the island is considerably higher owing to orographic influences (LHIB 2002).

Landform and Geology

The LHIG consists of the rugged southern mountains, the lower elevation and less rugged central hills, the flat to undulating lowlands, the northern hills and offshore islands. The southern mountains are composed of basalt and tuff and rise to 875 m asl at the summit of Mt Gower. The central hills are predominantly basaltic, but also include some areas of calcarenite. The lowlands are composed mainly of calcarenite with small areas of basalt, alluvial clays and aeolian sands. The northern hills, like the other mountainous parts of the island, are composed mainly of basalt with small areas of tuff and calcarenite. The offshore islands comprise tuff and breccia.

Botanical studies

A detailed history of botanical studies on the LHIG is given in Pickard (1983). The following provides a brief summary of the major botanical studies since that publication. Interestingly, Pickard (1983) makes no mention of a pattern analysis of the LHIG vegetation undertaken by Clarke (1974), whose classification and ordination analysis, based upon data collected by himself and Pickard, indicated that the distribution of the flora of the LHIG was responding primarily to exposure, elevation and disturbance. Pickard (pers. comm. Jan 2020) subsequently performed his own pattern analyses of those data, which he included in his unpublished MSc thesis (Pickard 1978, not sighted) but which were omitted from his 1983 paper.

In the same year that Pickard published his landmark study and map of the vegetation of the LHIG (Pickard 1983), Rodd and Pickard (1983) published a census of LHIG vascular plants and Pickard (1983a) undertook a subjective assessment of the rareness and threat status of the LHIG vascular flora. Pickard (1984) described the spatial and temporal distribution of exotic plants on the LHIG (see the discussion of LHIG weeds below).

The most notable botanical study since Pickard (1983) is the monograph of the vascular flora of the LHIG by Green (1994), completed as part of the *Flora of Australia* series. More recently, rare plant surveys were undertaken by Hutton (2001, 2005) who undertook extensive traverses to identify and document the location and size of populations of a suite of threatened and rare plant species. Hunter (2002) and Hunter and Hodgson (2005) undertook a review, based upon field validation, of the vegetation associations of parts of the Settlement area as part of the public exhibition of a proposed map of significant native vegetation (based upon Pickard's 1983 map). The floristics and structure of the mossy cloud forest of the Mt Gower summit was studied by Harris *et al.* (2005). The Lord Howe Island Biodiversity Management Plan (DECC 2006, 2007) provides detailed information on significant flora and vegetation communities. The vegetation of several of the offshore islands of the LHIG is described in detail in Carlile and Priddel (2013a–f) and Carlile *et al.* (2013).

Methods

Update of Pickard mapping and extant vegetation linework

Digital aerial imagery of the LHIG, at 10-cm resolution, captured using Airborne Digital Sensor (ADS40 Digital Image Acquisition System, by Leica Geosystems®), became available from LPI in January 2012. Using this imagery, aerial photography interpretation (API) was undertaken for this project using ArcGIS (versions 9.0 and 10.1; ESRI™) with an orthorectified stereo image (non-stereo imagery was sometimes used, particularly when viewing very rugged terrain) in normal colour and an enhanced image which was stretched in the 600–700-nm range to improve resolution of patterns in the vegetation.

Using the digital version of the Pickard (1983) vegetation map as a template, the ADS40 imagery was used to refine the spatial accuracy of the extent of vegetation of Pickard's linework. This included trimming areas of the Pickard linework where it extended beyond extant vegetation or land mass and adding areas such as isolated trees and smaller remnants of vegetation that were not mapped by Pickard. This produced a refined draft map that incorporated Pickard's polygons and attributions.

Site selection

A stratified random sampling design was employed using the refined Pickard linework described above, based upon the assumption that the identified vegetation types broadly represent a surrogate for underlying environmental variables. The number of sites to be sampled within each vegetation type was weighted by area. Vegetation types with small total areas were allocated a minimum of one site, whereas vegetation types with larger areal extents were allocated a proportionately greater number of sites. Not all sites that were selected were surveyed, and the actual number of sites completed in some vegetation types varied from the number allocated for a number of reasons, including access and time constraints, the detection of dissimilar vegetation patterns within individual polygons, and opportunistic survey of vegetation types detected in the course of field survey. Table 1 summarises the number of full floristic and rapid floristic survey sites planned and completed for each Pickard vegetation type.

Field survey

Sampling of floristic sites was undertaken during July 2013. Site coordinates were uploaded into hand-held GPS units to facilitate navigation to each site.

Full floristic surveys

Floristic data were gathered within a 20m × 20m quadrat positioned as close as possible to the pre-selected site location. Biophysical information including slope, aspect, geology, lithology and evidence of disturbance were recorded. Vegetation structural information (height range, dominant species, foliage cover) was recorded for each discernible vegetation stratum, and all vascular plant species present within the quadrat were recorded and assigned a modified Braun-Blanquet (1932) cover-abundance score between 1 and 6 as follows:

Score	Cover
1	<5% projected foliage cover – uncommon
2	<5% projected foliage cover – common
3	6–20% projected foliage cover
4	21–50% projected foliage cover
5	51–75% projected foliage cover
6	76–100% projected foliage cover

Plant samples were taken for later examination when the correct identity was uncertain. Plant nomenclature and taxonomy followed that of the National Herbarium of NSW, Royal Botanic Gardens, Sydney (PlantNET 2019). Photographs were taken at each site for use in community profiles and for future reference.

Rapid floristic surveys

Rapid floristic sites were identical to full floristic sites in positioning of the site and collection of locality information. However, the only floristic data recorded were up to six dominant species in the upper tree stratum, and up to three dominant species in each lower stratum, along with an estimate of the percentage foliage cover of each stratum. Photographs were taken at each site for future reference.

Data entry

All the information collected during full floristic and rapid floristic surveys was entered directly into the NSW Government central flora database (BioNet Vegetation Information System [VIS]), which underpins all native vegetation regulation and assessment in NSW (see http://www.environment.nsw.gov.au/research/Vegetationinformationsystem.htm [Accessed 10 Feb 2020]).

Data analysis

Data from 86 full floristic sites and 105 rapid floristic sites (using canopy taxa only) were investigated using a hierarchical agglomerative clustering strategy available in the software PATN (Belbin 1990, 1995) to determine the main floristic groups for the study area. Separate full floristic and canopy-only (combining canopy data from all sites) analyses were undertaken. Exotic taxa were included in the full floristic analysis. The Bray-Curtis association measure (Bray & Curtis 1957) was used to determine similarity of sites. A hierarchical classification of sites was then derived from a clustering strategy using a beta value of –1 in a flexible unweighted pair group arithmetic averaging (UPGMA) analysis. A nearest-neighbour analysis was then used to identify potentially misclassified sites, and a fidelity analysis applied to the resultant floristic groups, arising from the full floristic analysis, to identify diagnostic (indicator) species for each group (Bedward 1999).

Final community list

At the completion of floristic analyses, a complete vegetation community list for the LHIG was compiled by merging or splitting full floristic and canopy-only groups, and adding those vegetation types or mapping units that were not sampled during the current survey but were recognised and described in previous surveys (viz. Pickard 1983; Hutton 2001; DECC 2007). Note that the terms ‘vegetation community’, ‘vegetation type’ and ‘mapping unit’, may be used interchangeably, except where ‘mapping unit’ refers to a non-vegetation feature, such as Sand Beach, Boulder Beach, Cliff, and so on.

API and attribution of polygons

The linework for the vegetation map was reattributed using the resultant complete list of vegetation communities and other map units. Linework was revised where necessary and equivalence to Pickard (1983) and DECC (2007) communities allocated where possible.

Preparation of community profiles

Detailed profiles of each LHIG vegetation community sampled and recognised in this study, and for which floristic and physiognomic data were available, were prepared. A summary of the information contained in each profile is provided below (see Appendix 1 Community profiles). Those communities that were not sampled or visited during the current survey are listed but a detailed community profile is not provided.

Table 1 Floristic survey site allocation based on refined Pickard (1983) mapping. 'Area' is the area of each vegetation type mapped. For Full floristic and Rapid floristic sites, 'Planned' is the number of pre-selected survey sites and 'Completed' is the number of sites done during this study. Note that only those Pickard vegetation types in which floristic sites were selected are listed here.

Pickard (1983) vegetation type		Area (ha)	Full floristic sites		Rapid floristic sites	
Code	**Name**		**Planned**	**Completed**	**Planned**	**Completed**
Ac	*Aegiceras corniculatum*	2.0	1	2	2	2
Ax	*Atriplex cinerea*	0.8	0	0	1	0
BBB	Basalt boulder beach	15.9	1	1	0	0
BhDf	*Bubbia howeana – Dracophyllum fitzgeraldii*	27.9	3	1	2	2
C/CBB	Calcarenite/coral boulder beach	6.8	0	0	2	1
Ca	*Cassinia tenuifolia*	26.2	2	2	2	2
Ca-Pp	*Cassinia tenuifolia / Poa poiformis*	9.0	4	4	4	6
Cf	*Cleistocalyx fullageri*	136.2	5	5	13	11
Cg	*Cryptocarya gregsonii*	6.1	1	1	1	0
Cl	*Cyperus lucidus*	3.4	0	0	0	1
Cliffs	Cliffs	169.0	8	7	4	3
Cq	*Chionanthus quadristamineus*	92.9	4	2	7	2
Cq-Hb	*Chionanthus quadristamineus / Howea belmoreana*	7.1	2	1	3	3
CSB	Coral sand and beach	28.0	0	6	1	0
DaCt	*Drypetes australasica – Cryptocarya triplinervis*	394.4	15	15	22	19
DaCtC	*Drypetes australasica – Cryptocarya triplinervis* (calcarenite variant)	1.9	1	1	0	2
DaCtX	*Drypetes australasica – Cryptocarya triplinervis* (exposed variant)	66.5	5	6	13	12
DfMn	*Dracophyllum fitzgeraldii – Metrosideros nervulosa*	43.1	2	2	3	3
DfMn Lm-DaCt	*Dracophyllum fitzgeraldii – Metrosideros nervulosa* / Lowland Mixed Forest / *Drypetes australasica – Cryptocarya triplinervis*	4.1	0	0	2	2
Dv	*Dodonaea viscosa*	7.7	1	0	3	2
Hb	*Howea belmoreana*	60.5	3	3	3	2
Hc	*Hedyscepe canterburyana*	32.2	1	1	1	0
Hf	*Howea forsterana*	187.3	6	8	13	12
Hf-Cq	*Howea forsterana / Chionanthus quadristamineus*	2.3	0	1	1	1
Hf-Hb	*Howea forsterana / Howea belmoreana*	2.3	0	0	2	1
LM	Lowland Mixed Forest	196.4	13	12	10	11
Lp	*Lagunaria patersonia*	5.0	0	0	1	1
MFH	Mixed Fern and Herb	8.5	0	0	1	0
Mh	*Melaleuca howeana*	25.4	4	2	2	0
Pf	*Pandanus forsteri*	20.8	2	2	2	2
Pp	*Poa poiformis*	13.8	0	1	2	2
Total			**84**	**86**	**123**	**105**

Results

Field survey

A total of 191 survey sites (86 full floristic and 105 rapid floristic) was sampled during this study. Figure 2 shows the location of all survey sites. Overall, 222 plant taxa were recorded in floristic sites, including three threatened species and 47 exotic species (Appendix 2).

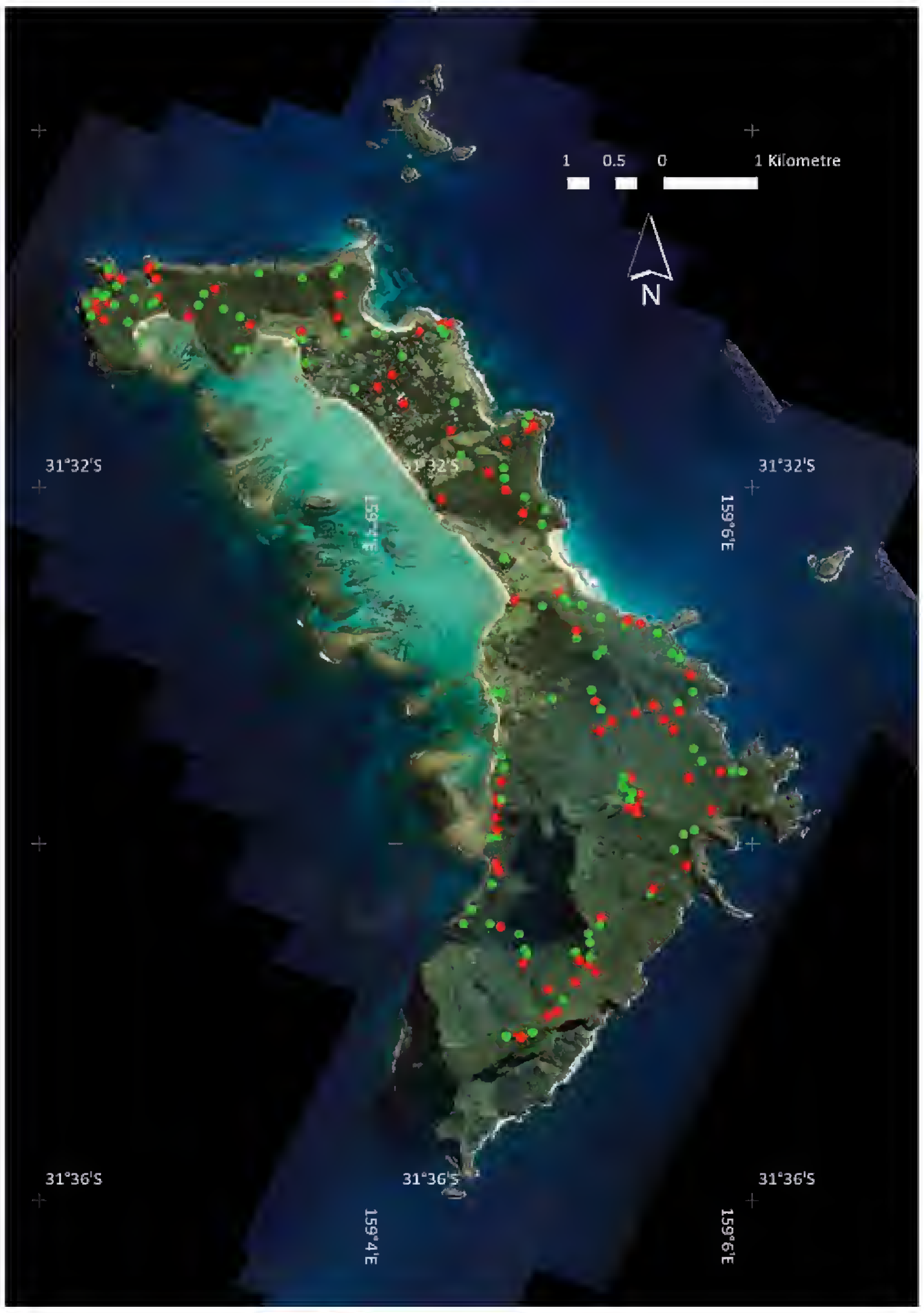


Fig. 2. Location of floristic survey sites. Red dots = full floristic sites; Green dots = rapid floristic sites

Data analysis

A dendrogram resulting from the numerical analysis of all data from the full floristic sites is shown in Figure 3. Twenty-four plant communities were derived at a dissimilarity measure of 0.65. A twenty-fifth group was excluded as it represented recent post-disturbance regeneration (see Figure 3). Two major groupings, split on the basis of relative species richness, were apparent in the full floristic dendrogram. The first grouping comprised communities with low species richness, including coastal grasslands and sedgelands, swamp forests and saltmarsh, and fernlands and shrublands of exposed, rocky areas. The second grouping contained species-rich oceanic rainforests of the lowlands and southern and northern hills, and montane cloud forests of the southern mountains. Within these two major groupings five sub-groups were discernible:

- Grasslands, herblands and shrublands of coastal areas. Includes beach strandline grasslands, and sedgelands, herblands and shrublands of beaches, headlands and cliffs in near-coastal areas.
- Wetlands of coastal creeks and estuaries. Includes Sallywood Swamp Forest, mangrove and saltmarsh.
- Heathlands/Shrublands of rocky areas. A group of heathland, shrubland and fernland communities ranging from low to high altitudes on steep slopes of rocky coastal hills and ridges of the southern mountains.
- Oceanic Cloud Forests. Includes the cloud forests of the summit plateaux of Mt Gower and Mt Lidgbird.
- Oceanic Rainforests. A large grouping of Oceanic Rainforests distributed across low to high altitude areas.

Analysis of canopy-only data from all 191 floristic sites resulted in the recognition of three additional communities: Group 3 – Grey Mangrove low estuarine forest; Group 4 – River Mangrove low estuarine forest; and Group 19 – *Pandanus – Metrosideros* riparian forest. A dendrogram of the canopy-only group analysis is provided in Figure 4. The remaining canopy-only groups were equivalent to existing full floristic groups.

A saltmarsh community (Community 7: Saltwater Couch saltmarsh of poorly drained, brackish flats) and two rainforest communities (Community 19: Maulwood – Kentia Palm – Cotton-wood – Greybark lowland forest; and Community 22: Hill Rose – Forky-tree forest of rocky creeks and slopes) that had not been recognised in previous studies were identified and mapped in the current study.

Final community list

This survey has resulted in the recognition of 39 mapping units for the LHIG. This list is compiled from:

- 19 mapping units formed from the full floristic analysis, including seven (7) mapping unit variants that were identified in five (5) of these floristic groups;
- Three (3) mapping units from analysis of canopy-only floristic data;
- Four (4) mapping units recognised by Pickard (1983), Hutton (2001) or DECC (2007) that are mapped but were not sampled in this survey.

Three map units identifying non-specific native vegetation (Environmental Plantings, Native Regeneration and Native Remnant) and 10 map units representing physiographic features or non-native vegetation were also delineated during this study. Table 2 presents the complete listing of vegetation communities (map units) along with their equivalence to Pickard (1983) and DECC (2007) vegetation types, where relevant.

Waterfall communities are described as occurring on vertical cliffs on the northern and western faces of Mt Gower, down to approximately 500 m asl (DECC 2007). The main plant species present are *Blechnum geniculatum*, *Blechnum howeanum*, *Machaerina insularis* and *Elatostema grande*. These communities are not included in this map and report, as they are of extremely restricted occurrence, generally inaccessible, and cannot be detected using API.

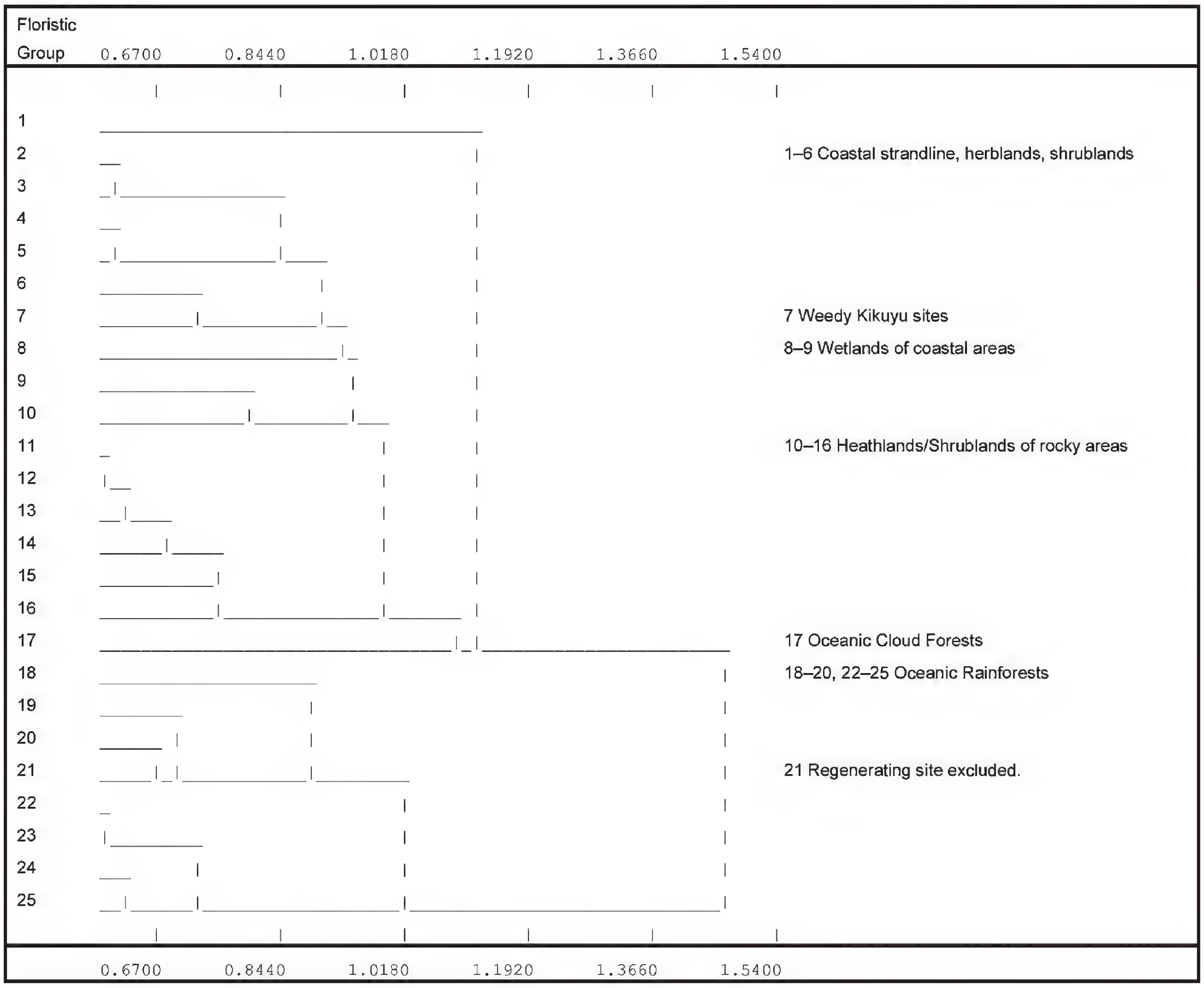

Floristic Group
0.6700
0.8440
1.0180
1.1920
1.3660
1.5400
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
1–6 Coastal strandline, herblands, shrublands
7 Weedy Kikuyu sites
8–9 Wetlands of coastal areas
10–16 Heathlands/Shrublands of rocky areas
17 Oceanic Cloud Forests
18–20, 22–25 Oceanic Rainforests
21 Regenerating site excluded.

Fig. 3. Dendrogram from analysis of full floristic sites.

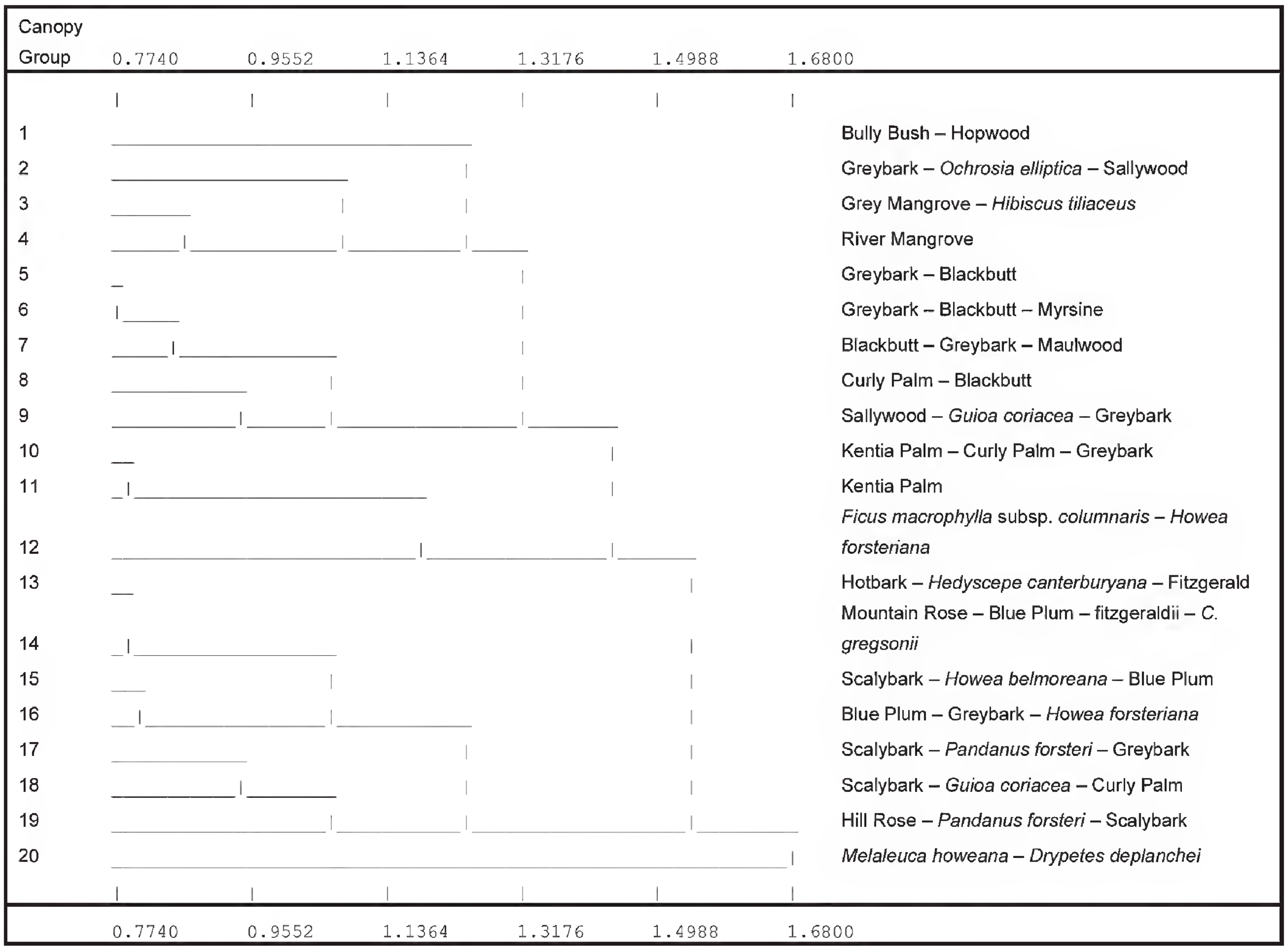

Canopy Group
0.7740
0.9552
1.1364
1.3176
1.4988
1.6800
1 Bully Bush – Hopwood
2 Greybark – *Ochrosia elliptica* – Sallywood
3 Grey Mangrove – *Hibiscus tiliaceus*
4 River Mangrove
5 Greybark – Blackbutt
6 Greybark – Blackbutt – Myrsine
7 Blackbutt – Greybark – Maulwood
8 Curly Palm – Blackbutt
9 Sallywood – *Guioa coriacea* – Greybark
10 Kentia Palm – Curly Palm – Greybark
11 Kentia Palm
12 *Ficus macrophylla* subsp. *columnaris* – *Howea forsteriana*
13 Hotbark – *Hedyscepe canterburyana* – Fitzgerald
14 Mountain Rose – Blue Plum – fitzgeraldii – *C. gregsonii*
15 Scalybark – *Howea belmoreana* – Blue Plum
16 Blue Plum – Greybark – *Howea forsteriana*
17 Scalybark – *Pandanus forsteri* – Greybark
18 Scalybark – *Guioa coriacea* – Curly Palm
19 Hill Rose – *Pandanus forsteri* – Scalybark
20 *Melaleuca howeana* – *Drypetes deplanchei*

Fig. 4. Dendrogram from analysis of canopy-only data of all floristic sites.

Community profiles

Detailed profiles of each LHIG vegetation community sampled and recognised in this study, and for which floristic and physiognomic data were available, have been prepared to assist in the identification of these types in the field, particularly for environmental planning purposes. The detailed profiles are presented in Appendix 1.

Table 2 Vegetation communities identified in this study and their equivalence to previous classifications. The Community number is also the map unit number and code, and the community name is also the mapping unit name

Community number	Community name	Pickard (1983)	DECC (2007)
1	Coastal Spinifex – Dune Bean – Club Rush – *Melanthera biflora* – Saltwater Couch beach strandline grassland	Coral Sand Beach and Dune	Coral Sand Beach and Dune
2	*Melanthera biflora* – Saltwater Couch herbland/grassland on coral boulder beaches and rocky headlands	Calcarenite and Coral Boulder Beach	Calcarenite and Coral Boulder Beach
2	*Melanthera biflora* – Saltwater Couch herbland/grassland on coral boulder beaches and rocky headlands	Cliff	Cliff
3	Grey Saltbush shrubland of exposed talus slopes	*Atriplex cinerea* Orthophyll Dwarf Scrub	Saltbush *(Atriplex cinerea)* Dwarf Scrub
4	Chaff Flower – Ice Plant – Saltwater Couch – Pigface herbland/grassland of rock shelves and cliffs	*Ipomoea cairica – Carpobrotus glaucescens* Evergreen Broad-leaved Weedy Vegetation	*Ipomoea cairica – Carpobrotus glaucescens* Herbland
4	Chaff Flower – Ice Plant – Saltwater Couch – Pigface herbland/grassland of rock shelves and cliffs	Part of Cliff	Part of Cliff
5	Tea Tree shrubland on exposed rocky slopes	*Melaleuca howeana* Straight Narrow Sclerophyll Scrub	*Melaleuca howeana* Closed Scrub
6	Sallywood swamp forest of poorly drained, low-lying areas	*Lagunaria patersonia* Broad Orthophyll Sclerophyll Forest	Sallywood *Lagunaria patersonia* Closed Swamp Forest
7	Saltwater Couch saltmarsh of poorly drained, brackish flats	No equivalent	No equivalent
8	Bully Bush – Hopwood shrubland on shallow rocky soils	*Cassinia tenuifolia* Straight Narrow Sclerophyll Scrub	Bully Bush (*Cassinia tenuifolia*) Closed Scrub
8	Bully Bush – Hopwood shrubland on shallow rocky soils	*Dodonaea viscosa* Evergreen Broad Sclerophyll Scrub	*Dodonaea viscosa* Closed Scrub
9	Common Reed – Leafy Flat Sedge – Couch grassland or sedgeland of northern hills and offshore islands	*Cyperus lucidus* Sclerophyll Tall Grass	*Cyperus lucidus* Sedgeland
10	Fishbone Fern – Boat Vine – Bat's Wing Fern fernland on boulder slopes at cliff bases	Mixed Fern and Herb	Mixed Fern and Herb
11	Bully Bush – Tea Tree – Mountain Daisy rocky heathland of the southern mountains	Part of Cliff	Related to *Alyxia squamulosa – Coprosma inopinata* Dwarf Scrub
12a	Kentia Palm forest on coral sand and calcarenite	*Howea forsteriana* Megaphyllous Broad Sclerophyll Forest	Kentia Palm *Howea forsteriana* Closed Sclerophyll Forest
12b	Banyan – Kentia Palm forest on coral sand and calcarenite	*Howea forsteriana* Megaphyllous Broad Sclerophyll Forest	Kentia Palm *Howea forsteriana* Closed Sclerophyll Forest
13a	Hotbark – Fitzgerald gnarled mossy cloud forest	*Bubbia howeana – Dracophyllum fitzgeraldii* Gnarled Mossy Forest	*Bubbia howeana – Dracophyllum fitzgeraldii* Gnarled Mossy Forest
13b	Mountain palm low closed forest	*Hedyscepe canterburyana* Megaphyllous Broad Sclerophyll Forest	Big Mountain Palm *Hedyscepe canterburyana* Closed Sclerophyll Forest
13c	Fitzgerald – Mountain Rose low closed forest	*Dracophyllum fitzgeraldii – Metrosideros nervulosa* Evergreen Broad Sclerophyll Scrub	*Dracophyllum fitzgeraldii – Metrosideros nervulosa* Closed Scrub
14	Scalybark – Blue Plum – Curly Palm closed forest of sheltered slopes or valleys	*Cleistocalyx fullagarii* Rainforest	Scalybark (*Syzygium fullagarii*) Closed Forest
15a	Blue Plum – Curly Palm – Scalybark closed forest on rocky slopes	*Chionanthus quadristamineus* Rainforest	Blue Plum *Chionanthus quadristamineus* Closed Forest

Community number	**Community name**	**Pickard (1983)**	**DECC (2007)**
15a	Blue Plum – Curly Palm – Scalybark closed forest on rocky slopes	Part of *Howea belmoreana* Megaphyllous Broad Sclerophyll Forest	Part of Curly Palm *Howea belmoreana* Closed Sclerophyll Forest, *Pandanus forsteri* Closed Sclerophyll Forest
15b	Forky-tree closed forest along gullies	*Pandanus forsteri* Megaphyllous Broad Sclerophyll Forest	*Pandanus forsteri* Closed Sclerophyll Forest
16a	Scalybark – Curly Palm – Greybark – Cedar – Maulwood – Forky-tree lowland mixed closed forest on slopes of the southern mountains	Lowland Mixed Rainforest	Lowland Mixed Closed Forest
16b	Curly Palm closed sclerophyll forest	*Howea belmoreana* Megaphyllous Broad Sclerophyll Forest	Curly Palm *Howea belmoreana* Closed Sclerophyll Forest
17a	Greybark – Blackbutt rainforest	*Drypetes australasica – Cryptocarya triplinervis* Rainforest	Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Closed Forest
17b	Greybark – Blackbutt low closed forest on exposed basalt slopes	*Drypetes australasica – Cryptocarya triplinervis* Exposed Facies Rainforest	Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Low Closed Forest on Exposed Basalt
17c	Greybark – Blackbutt low closed forest on exposed calcarenite	*Drypetes australasica – Cryptocarya triplinervis* Exposed Calcarenite Facies Rainforest	Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Low Closed Forest on Exposed Calcarenite
18	Kentia Palm – Greybark rainforest of low to mid-altitude slopes	*Drypetes australasica – Cryptocarya triplinervis* Rainforest	Kentia Palm (*Howea forsteriana*) Closed Sclerophyll Forest
18	Kentia Palm – Greybark rainforest of low to mid-altitude slopes	*Howea forsteriana* Megaphyllous Broad Sclerophyll Forest	Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Closed Forest
19	Maulwood – Kentia Palm – Cotton-wood – Greybark lowland forest	No equivalent	No equivalent
20	Grey Mangrove low open woodland of brackish creeks	*Avicennia marina* var. *australasica* Open Broad Sclerophyll Scrub	Mangrove (*Avicennia marina* var. *australasica*) Open Swamp Scrub
21	River Mangrove tall shrubland of brackish creeks	*Aegiceras corniculata* Broad Sclerophyll Swamp Scrub	Mangrove *Aegicerus corniculata* Closed Swamp Scrub
22	Hill Rose – Forky-tree forest of rocky creeks and slopes	No equivalent	No equivalent
23	*Poa poiformis* tussock grassland of offshore islands and exposed coastal slopes	*Poa poiformis* Orthophyll Short Grass	*Poa poiformis* Grassland
24	*Pouzolzia australis* – Kava closed shrubland on exposed wet rocky slopes	*Boehmeria calophleba – Macropiper excelsum* var. *psittacorum* Broad Orthophyll Scrub	*Boehmeria calophleba–Macropiper hooglandii* Closed Scrub
25	*Alyxia squamulosa – Coprosma inopinata* low shrubland on narrow exposed rocky ridges	No equivalent	*Alyxia squamulosa–Coprosma inopinata* Dwarf Scrub
26	Black Plum – King Fern low closed forest of the southern mountains	Part of *Cryptocarya gregsonii* Rainforest	Part of *Cryptocarya gregsonii* Closed Forest
Boulder Beach	Beach	Basalt boulder beach	Basalt boulder beach
Cliff	Cliff	Cliff	Cliff, waterfall cliff
Dam	Dam	–	–
Ep	Environmental plantings	–	–
Estuary	Estuary	–	–
Ex	Exotic	–	–
Ls	Landslip	–	–
Ng	Native regeneration	Part of Disturbed areas?	–
Np	Plantation	–	–
Nr	Native remnant	Part of Disturbed areas?	–
Rock	Rock	Cliff	Cliff
Sand Beach	Beach	Coral sand beach and dune	Coral sand beach and dune
Water	Water	–	–

Discussion

Map resolution

This study has resulted in the production of a high-resolution vegetation community map for the LHIG with greatly improved accuracy of linework compared with existing mapping. As an indication of the increase in the level of detail, the Pickard (1983) vegetation map comprised 321 individual polygons, whereas the new vegetation map comprises 1840 polygons of sufficient accuracy to support environmental planning, particularly within the Settlement area where spatial accuracy in the delineation of native vegetation is critical. Figure 5 provides a graphic comparison of the accuracy of the two vegetation maps by overlaying both sets of linework on an aerial image of part of the Settlement area. The high-resolution ADS40 imagery used in this study also enabled the current study to map much smaller vegetated remnants (down to crowns of individual paddock trees in some instances). By comparison, the minimum polygon size in the Pickard (1983) map is about 0.1 ha. The high resolution of this mapping will greatly improve the ability of the LHIB to assess, manage and monitor vegetation communities and their responses to weed management, biosecurity, conservation assessment, ecological restoration and threat mitigation.

The current study utilised stratified, random sampling of floristic survey data to inform floristic analyses, resulting in a new vegetation community classification for the LHIG. Although this approach differed from the iterative, field traverse-based approach undertaken by Pickard (1983), the latter classification is considered robust and, indeed, underpinned initial site selection and linework attribution in the current study. Pickard's classification, in conjunction with observations made during intensive fieldwork for the current study, also strongly influenced post-analysis recognition of 'mappable' variants within vegetation communities. The only departure from consensus with this earlier work is where our floristic analysis identified a distinct lowland rainforest community (Community 19).

Threats

Threats to the vegetation of the LHIG include climate change (including rises in sea level), exotic pathogens, feral animals and weeds (see below). Keith (2004), Auld and Hutton (2004), Harris *et al*. (2005) and Auld and Leishman (2015) discuss the impact of climate change upon the oceanic cloud forests of LHI. The summits and upper slopes of the southern mountains on LHI are regularly and consistently shrouded in cloud, creating the moist, cool environment required by the unique vegetation communities that occur there. One potential effect of climate change is an upward shift in the elevation at which clouds form, with obvious negative implications for the moisture-dependent cloud forest ecosystems (Auld and Hutton 2004, Auld and Leishman 2015). Other effects of climate change include a predicted increase in the frequency and severity of droughts and storm events, which could have a significant impact on the vegetation and plants of the LHIG, and sea-level rise, which potentially threatens low-lying vegetation communities (DECC 2007).

The exotic pathogen *Phytophthora cinnamomi* has recently been recorded from the main island and there are a number of plant taxa endemic to the LHIG that are closely related to taxa in other parts of the world that have been severely affected by *P. cinnamomi* (Auld and Hutton 2004). Strategies aimed at, among other things, controlling the entry and spread of *P. cinnamomi* have been developed and implemented for the LHIG (LHIB 2014, 2015; Department of the Environment 2014; AECOM 2016). For instance, boot-cleaning stations are now provided at the beginning of walking tracks into the southern mountains.

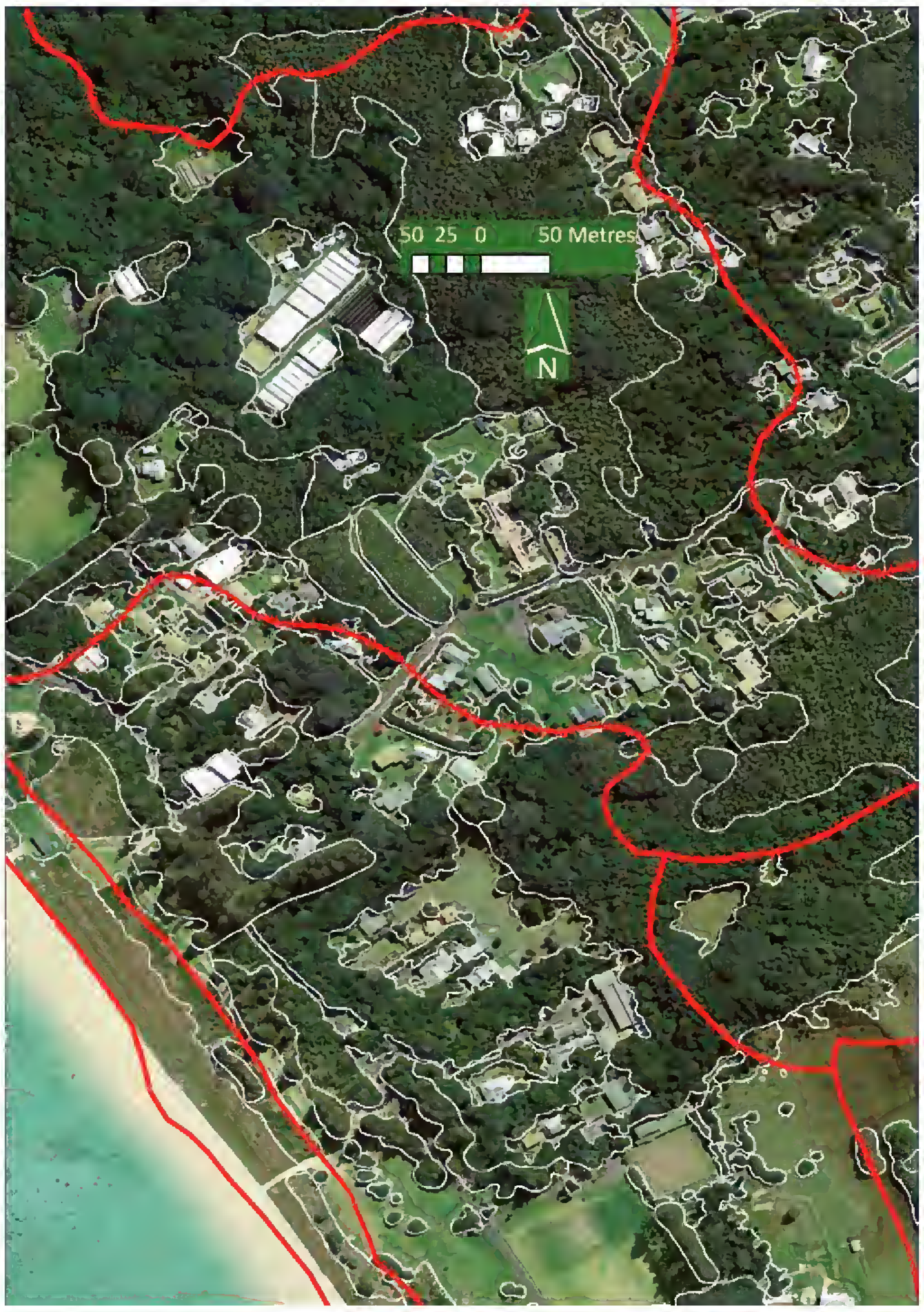


Fig. 5. Comparison of the current mapping linework (white lines) with the Pickard (1983) linework (red lines) in part of the Settlement area. The location of this area is shown in Figure 1 above. The underlying image is the 2012 ADS40 10 cm imagery used in the current study.

The fungal pathogen Myrtle Rust, *Austropuccinia psidii,* was detected for the first time on Lord Howe Island in October 2016. Fortunately, early detection and implementation of a rigorous control program appears, to date, to have successfully eradicated it (Makinson 2018).

The threat to the native vegetation of the LHIG by feral rodents (Black Rat *Rattus rattus* and House Mouse *Mus musculus*) is well documented. The draft Lord Howe Island Rodent Eradication Plan (LHIB 2009) provides a detailed review of the impact of rodents on the biodiversity of the

LHIG. Auld *et al.* (2010) found that juvenile palms were rare or absent in areas unbaited for rodents. Predation on seeds of component species of the cloud forest, especially the endemic Big (*Hedyscepe canterburyana*) and Little (*Lepidorrhachis mooreana*) Mountain Palms, is a threat to the survival of the community (Auld and Leishman 2015). A program of rodent eradication was proposed (LHIB 2009) to eliminate this threat to the native vegetation of the LHIG. The eradication program was implemented in 2019, with initial results indicating outstanding success (LHIREP 2019).

Weeds

Weeds are a common and significant component of some vegetation communities of the LHIG, particularly coastal strandlines and headlands, shrublands of the southern mountains, regenerating vegetation on landslips and other disturbed areas, and near human settlement (Pickard 1984, Le Cussan 2006, LHIB 2016a). In total, 47 weed species were recorded in floristic sites during the current survey (21% of the number of all plant species in floristic sites). Where a weed species constitutes a significant component of, or poses a serious threat to, a LHIG vegetation community, that species is listed in the relevant community profile (see Appendix 1).

Since 2004, the LHIB has implemented a program to attempt the eradication of 25 priority invasive weed species. As a result of this program, by 2014 the impact of dense and widespread weed infestations on the LHIG had been reduced by an estimated 80% (LHIB 2006, 2016a). Based on floristic surveys and general field observations during the current study, the most important weeds on LHI are (in alphabetical order by scientific name): Crofton Weed (*Ageratina adenophora*), Ground Asparagus (*Asparagus aethiopicus*), Coastal Morning Glory (*Ipomoea cairica*), Formosan Lily (*Lilium formosanum*), Kikuyu (*Cenchrus clandestinus*), Cherry Guava (*Psidium cattleyanum* var. *cattleyanum*) and Buffalo Grass (*Stenotaphrum secundatum*). Our observations broadly concur with findings reported in the draft 2016 Weed Management Strategy (LHIB 2016b).

Threatened and extinct plant species

Eleven species of plant recorded from the LHIG are listed as Endangered or Critically Endangered under the NSW *Biodiversity Conservation Act 2016* (*BC Act*). Six of these species are also listed as either Endangered or Critically Endangered under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*). Table 3 lists the threatened plant species and their status under NSW and Commonwealth legislation.

Two plant species, *Hypolepis elegans* and *Solanum bauerianum*, are listed as presumed extinct under the *BC Act*. *Solanum bauerianum* is now considered to be extinct globally, and has not been relocated, despite surveys in areas of its past distribution on the LHIG (Pickard 1983a; Hutton 2005). The decline and extinction of *Solanum bauerianum* may have been caused by clearing and fragmentation of habitat for settlement, and consumption by cattle, goats, rodents and pigs (NSW Scientific Committee 2010). Although *Hypolepis elegans* is listed as presumed extinct in NSW, collections of this species have been made from LHI as recently as 2018 (AVH 2020). Both Green (1994) and Hutton (2010b) record *H. elegans* as "common, especially in open areas". Most recently, Hutton considers it to be 'not common but still fairly widespread' (I. Hutton pers. comm. *per* C. Stehn Feb 2020).

The LHI Biodiversity Management Plan (DECC 2007) lists several native plant taxa as presumed extinct on LHI, none of which are listed under either the *BC Act* or the *EPBC Act*. One species on that list, *Marsdenia tubulosa*, has since been collected on Mt Gower (AVH 2020). The other species listed in the Biodiversity Management Plan are common in other parts of the world and are either represented by one or two early records from LHI (*Paspalum vaginatum*, *Tetragonia implexicoma*) or mentioned as present on LHI in an early report (*Scaevola taccada*) (Green 1994). Similarly, Rodd & Pickard (1983) provide a list of plant taxa considered native to, but now presumed extinct on, the LHIG. One species on that list, Lord Howe Island Morning Glory (*Calystegia affinis*), has since been collected on LHI and is listed as Critically Endangered under the *BC Act* and *EPBC Act* (Table 3). *Solanum bauerianum* has since been listed as Presumed Extinct (Table 3). *Pandanus pedunculata* (now *P. tectorius*) was known from a single plant on LHI, which died in 1975 (Green 1994), and *Pseuderanthemum grandiflorum* (now *P. pelagicum*) is native to Vanuatu and the LHI specimen is likely a mis-labelled collection from Vanuatu (Green 1994).

Three threatened species were recorded in floristic plots during the current survey:

> Mountain Xylosma (*Xylosma parvifolia*)
> Endangered (*BC* & *EPBC Acts*)
>
> A shrub to 2 m tall with rounded, serrate leaves, that grows on ridges in the southern mountains (DECC 2007). In the present survey it was recorded in Community 10. The site was located on a steep narrow ridge above the Goathouse and below Mt Lidgbird.
>
> Little Mountain Palm (*Lepidorrhachis mooreana*)
> Critically Endangered (*BC* & *EPBC Acts*)
>
> A stout, dwarf palm to 2 m tall growing in sheltered closed forests of the mountain summits (DECC 2007). In the present survey it was recorded as a dominant in Community 13b. It was recorded in one full floristic site on the ascent to Mt Gower.
>
> *Geniostoma huttonii* Endangered (*BC* & *EPBC Acts*)
>
> A scrambling shrub to 1 m tall that grows in the southern mountains on shaded cliffs from mid- to high altitudes. In the present survey it was recorded in Community 14.

Table 3 Threatened and extinct plant species recorded for the LHIG. CE = Critically Endangered; E = Endangered; Ex = Extinct

Scientific name	**Common name**	**Status**	
		BC Act	***EPBC Act***
Anthosachne kingiana subsp. kingiana (listed as *Elymus multiflorus* subsp. *kingianus*)	Phillip Island Wheat Grass	CE	CE
Caesalpinia bonduc	Knicker Nut	E	
Calystegia affinis	Lord Howe Island Morning Glory	CE	CE
Carmichaelia exsul	Lord Howe Island Broom	E	
Chamaesyce psammogeton	Sand Spurge	E	
Coprosma inopinata	Small-leaved Currant Bush	E	
Geniostoma huttonii	Hutton's Geniostoma	E	E
Hypolepis elegans		Ex	
Lepidorrhachis mooreana	Little Mountain Palm	CE	CE
Melicope vitiflora	Coast Euodia	E	
Polystichum moorei	Rock Shield Fern	E	E
Solanum bauerianum		Ex	
Xylosma parvifolia	Mountain Xylosma	E	E

Threatened Ecological Communities

Lord Howe Island supports two vegetation communities that are currently listed as Critically Endangered Ecological Communities (CEEC) under the *BC Act*: Gnarled Mossy Cloud Forest on Lord Howe Island (Community 13 of this study, occurring on the summit plateaux and ridges of Mts Gower and Lidgbird), and *Lagunaria* Swamp Forest on Lord Howe Island (Community 6 of this study), which was formerly more widespread on the low-lying flats within the Settlement area but has suffered severe decline since human settlement. No LHIG vegetation communities are currently listed as threatened under the *EPBC Act*.

Gnarled Mossy Cloud Forest was mapped by Pickard (1983) as occupying 28 ha of the Mt Gower summit plateau and a very narrow strip along the western edge of the summit of Mt Lidgbird. The current study mapped 26 ha of Community 13a Hotbark – Fitzgerald gnarled mossy cloud forest, similar to the area identified by Pickard (1983). However, floristic analyses undertaken during the current study did not separate two other distinct communities that were recognised by Pickard (1983) from Community 13a of the current study: *Hedyscepe canterburyana* closed forest and *Dracophyllum – Metrosideros* closed scrub. These two communities were recognised, post-analysis, as mappable variants of Community 13 in the current study: 13b Mountain Palm low closed forest and 13c Fitzgerald – Mountain Rose low closed forest. Although some parts of the latter two communities would represent the Gnarled Mossy Cloud Forest CEEC, other parts, especially lower elevation occurrences, would not.

Lagunaria Swamp Forest was mapped by Pickard (1983) in five locations, covering a total of 6 ha. Pickard noted at the time that all remnants had been destroyed or were sufficiently disturbed to render successful natural regeneration unlikely. DECC (2007) noted the existence of one remnant stand near Cobbys Corner, and remnant trees remaining in some other stands. The current study mapped very small remnants of this type on a swampy flat at North Bay, along Settlement Creek, behind Pinetrees, near Cobbys Corner and at Soldier Creek. The total extent of all occurrences was only 0.8 ha.

Most vegetation communities recognised by the current study should be assessed for eligibility for listing as threatened ecological communities under the *BC Act*. Table 4 lists each community, its level of representation within the PPP and a threat status based upon a subjective analysis of the overall extent of the community, the current level of formal protection, and the perceived vulnerability of each community to known threatening processes. Those communities with an assigned threat status of High or Very High in Table 4 should be assessed for eligibility for listing as threatened ecological communities. Structural, floristic, habitat, distribution and threat information for all communities is provided in the vegetation community profiles (Appendix 1).

Vegetation classification database

The vegetation classification for the LHIG arising from this study should be incorporated into the NSW Vegetation Classification module of the BioNet Vegetation Information System (VIS), the government repository of all vegetation and floristic data and which underpins native vegetation regulation and assessment in NSW (see www.environment.nsw.gov.au/research/Vegetationinformationsystem.htm [Accessed 10 Feb 2020]). In order to achieve this, the classification requires submission to the NSW Plant Community Type Change Control Panel (PCTCCP) for approval. For details refer to http://www.environment.nsw.gov.au/research/PCTchangecontrol.htm (Verified 10 Feb 2020). The PCTCCP was established to maintain and improve the quality of the NSW Master Plant Community Type Classification that is managed within the Vegetation Classification database. Inclusion of the new LHIG vegetation classification into the database would ensure ongoing management, maintenance and review of this valuable dataset.

Table 4 Conservation status of the plant communities of the LHIG, and representation in the PPP. Threat status is based on a subjective analysis of the extent of a community, its current level of formal protection, and perceived vulnerability to threatening processes; CEEC indicates a Critically Endangered Ecological Community currently listed under the *BC Act*.

Community number	Community name	Representation in PPP	Threat status
1	Coastal Spinifex – Dune Bean – Club Rush – *Melanthera biflora* – Saltwater Couch beach strandline grassland	Poor (16%)	High
2	*Melanthera biflora* – Saltwater Couch herbland/grassland on coral boulder beaches and rocky headlands	Good (58%)	Moderate
3	Grey Saltbush shrubland of exposed talus slopes	Good (60%)	High
4	Chaff Flower – Ice Plant – Saltwater Couch – Pigface herbland/grassland of rock shelves and cliffs	Very Good (95%)	High
5	Tea Tree shrubland on exposed rocky slopes	Very Good (97%)	Low
6	Sallywood swamp forest of poorly drained, low-lying areas	Very Poor (<1%)	CEEC
7	Saltwater Couch saltmarsh of poorly drained, brackish flats	None (0%)	Very High
8	Bully Bush – Hopwood shrubland on shallow rocky soils	Very Good (98%)	Moderate
9	Common Reed – Leafy Flat Sedge – Couch grassland or sedgeland of northern hills and offshore islands	Very Poor (<1%)	Very High
10	Fishbone Fern – Boat Vine – Bat's Wing Fern fernland on boulder slopes at cliff bases	Very Good (98%)	Moderate
11	Bully Bush – Tea Tree – Mountain Daisy rocky heathland of the southern mountains	All (100%)	High
12a	Kentia Palm forest on coral sand and calcarenite	Moderate (33%)	Very High
12b	Banyan – Kentia Palm forest on coral sand and calcarenite	Good (70%)	Very High
13a	Hotbark – Fitzgerald gnarled mossy cloud forest	All (100%)	CEEC
13b	Mountain Palm low closed forest	All (100%)	Very High (CEEC in part)
13c	Fitzgerald – Mountain Rose low closed forest	All (100%)	High (CEEC in part)
14	Scalybark – Blue Plum – Curly Palm closed forest of sheltered slopes or valleys	Very Good (98%)	High
15a	Blue Plum – Curly Palm – Scalybark closed forest on rocky slopes	Very Good (99%)	High
15b	Forky-tree closed forest along gullies	Very Good (98%)	Very High
16a	Scalybark – Curly Palm – Greybark – Cedar – Maulwood – Forky-tree lowland mixed closed forest on slopes of the southern mountains	Very Good (99%)	High
16b	Curly Palm closed sclerophyll forest	Very Good (98%)	High
17a	Greybark – Blackbutt rainforest	Very Good (83%)	Moderate
17b	Greybark – Blackbutt low closed forest on exposed basalt slopes	Medium	Moderate
17c	Greybark – Blackbutt low closed forest on exposed calcarenite	All (100%)	Very High
18	Kentia Palm – Greybark rainforest of low to mid altitude slopes	Very Good (93%)	High
19	Maulwood – Kentia Palm – Cotton-wood – Greybark lowland forest	None (0%)	Very High
20	Grey Mangrove low open woodland of brackish creeks	None (0%)	Very High
21	River Mangrove tall shrubland of brackish creeks	None (0%)	Very High
22	Hill Rose – Forky-tree forest of rocky creeks and slopes	All (100%)	High
23	*Poa poiformis* tussock grassland of offshore islands and exposed coastal slopes	All (100%)	High
24	*Pouzolzia australis* – Kava closed shrubland on exposed wet rocky slopes	All (100%)	Very High
25	*Alyxia squamulosa* – *Coprosma inopinata* low shrubland on narrow exposed rocky ridges	All (100%)	Very High
26	Black Plum – King Fern low closed forest of the southern mountains	All (100%)	Very High

Conclusion

This report describes the methodology and results of floristic survey, floristic analyses and classification, and high-resolution, fine-scale mapping of the vegetation communities of the LHIG. A total of 222 plant species, including 47 introduced species, were recorded from 191 floristic plots. All floristic data gathered during the project were entered into the BioNet Vegetation Information System flora survey database. The resultant vegetation classification and map identifies a total of 39 map units, including 26 native vegetation communities (plus seven variants within five of these communities) and 13 non-native vegetation or non-vegetation units. Three communities that had not been recognised in previous studies were identified in the course of this project: a saltmarsh community, a lowland rainforest community, and a rainforest community of rocky riparian sites. Detailed community profiles, containing structural, floristic, habitat, distribution and threat information, along with photographs and maps, were prepared to aid in field identification and assessment. Based upon threat information and level of formal protection within the Permanent Park Preserve, each community was allocated a threat status. Those assessed as having a 'High' or 'Very High' threat status should be considered for nomination as threatened ecological communities.

The high resolution of this mapping will greatly improve the ability of the LHIB to undertake detailed environmental planning and to assess, manage and monitor vegetation communities and their responses to weed management, biosecurity, conservation assessment, ecological restoration and threat mitigation throughout the LHIG.

Acknowledgements

We thank Dave Kelly (then Manager, Environment and Community Development, LHIB) for the inception, administration and organisation of the project. Sue Bower (Flora Management Officer, LHIB) and Hank Bower (Manager Environment – World Heritage) provided excellent assistance with planning field surveys as well as good company in the field and after work. Ian Hutton gave valuable assistance in the field and generously shared his deep knowledge of the flora of the LHIG. Christo Haselden, Nelson Retmock, Louis Shick, Bruce 'Gilly' Thompson, and John Trehy provided enthusiastic assistance with field work. Doug Binns assisted with the floristic analyses. Thanks also to Dave Kelly, Ian Hutton, Sue Bower and Hank Bower for critically reviewing both the vegetation map and the original accompanying report. Dr John Pickard provided a constructive review of this manuscript which has improved the final product.

References

AECOM (2016) *Draft Lord Howe Island Biosecurity Strategy 2016*. AECOM, Townsville, Qld.

AVH (2020) *Australia's Virtual Herbarium*, Council of Heads of Australasian Herbaria. Available at http://avh.chah.org.au (Accessed Feb 2020).

Auld, T. D. and Hutton, I. (2004) Conservation issues for the vascular flora of Lord Howe Island. *Cunninghamia* **8 (4)**: 490–500.

Auld, T. D. and Leishman, M. R. (2015) Ecosystem risk assessment for Gnarled Mossy Cloud Forest, Lord Howe Island, Australia. *Austral Ecology* **40**: 364–372.

Auld, T. D., Hutton I., Ooi, M. J. K. and Denham, A. (2010) Disruption of recruitment in two endemic palms on Lord Howe Island by invasive rats. *Biological Invasions* **12 (9)**: 3351–3361.

Bedward, M. (1999) *Fidel: A Utility to Profile Classification Groups in Terms of Attribute Fidelity.* Unpublished report for NSW National Parks and Wildlife Service Southern CRA Unit, Queanbeyan, NSW.

Belbin, L. (1990) *PATN Pattern Analysis Package*. CSIRO, Canberra.

Belbin, L. (1995) *PATN Technical Reference Manual*. CSIRO Division of Wildlife & Ecology, Canberra.

Braun-Blanquet, J. (1932) *Plant Sociology: The Study of Plant Communities*. Koeltz Scientific Books, Koenigstein. Translated, revised and edited by Fuller, G. D. & Conrad, H. S. (1983).

Bray, J. R. and Curtis, J. T. (1957) An ordination of upland forest communities of southern Wisconsin. *Ecological Monographs* **27**: 325–349.

Bureau of Meteorology (2015) Lord Howe Island meteorological data. Accessed online at http://www.bom.gov.au/climate/averages/tables/cw_200839.shtml (Verified 20 Jul 2016).

Carlile, N. and Priddel, D. (2013a) Seabird Islands No. 257: Tenth of July Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 86–87.

Carlile, N. and Priddel, D. (2013b) Seabird Islands No. 258: South Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 88–89.

Carlile, N. and Priddel, D. (2013c) Seabird Islands No. 257: Tenth of June Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 86–87.

Carlile, N. and Priddel, D. (2013d) Seabird Islands No. 260: Soldiers Cap, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 92–93.

Carlile, N. and Priddel, D. (2013e) Seabird Islands No. 261: Muttonbird Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 94–96.

Carlile, N. and Priddel, D. (2013f) Seabird Islands No. 262: Blackburn Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 97–99.

Carlile, N., Priddel, D. and Bower, H. (2013) Seabird Islands No. 256: Roach Island, Lord Howe Group, New South Wales. *Corella* **37 (4)**: 82–85.

Clarke, S. S. (1974) *Pattern Analysis of the Vegetation.* Appendix D, pages 37–46 **In** Recher, H. F. and Clarke, S. S. (Eds). *Environmental Survey of Lord Howe Island.* A report to the Lord Howe Island Board. The Australian Museum, Department of Environmental Studies, Sydney.

Department of the Environment (2014) *Threat Abatement Plan for Disease in Natural Ecosystems Caused by* Phytophthora cinnamomi. Commonwealth of Australia, Canberra. Available at https://www.environment.gov.au/biodiversity/threatened/publications/threat-abatement-plan-disease-natural-ecosystems-caused-phytophthora-cinnamomi (Verified 16 Jul 2016).

DECC (2007) *Lord Howe Island Biodiversity Management Plan.* Department of Environment and Climate Change (NSW), Sydney.

Green, P. S. (1994) *Flora of Australia. Vol. 49 Oceanic Islands. 1.* Australian Government Publishing Service, Canberra.

Harris, R., Cassis, G., Auld, T., and Hutton, I. (2005) Floristics and structure of the mossy cloud forest of Mt Gower summit, Lord Howe Island. *Pacific Conservation Biology* **11**: 246–256.

Hunter, J. (2002) *Vegetation and Habitat of Significance Within the Settlement area of Lord Howe Island.* An internal report for the Lord Howe Island Board. NSW Department of Environment and Conservation.

Hunter, J. and Hodgson, G. (2005) *Revised Vegetation Map of Lord Howe Island.* Metadata statement held by NSW Department of Environment and Conservation.

Hutton, I. (2001) *Rare Plant Surveys – Lord Howe Island.* A report prepared for the NSW Scientific Committee, Hurstville (Sydney), NSW.

Hutton, I. (2005) *Rare Plant Survey 2 – Lord Howe Island.* Unpublished report.

Hutton, I. (2008) *A Guide to World Heritage Lord Howe Island.* The author, Lord Howe Island.

Hutton, I. (2010a) *A Field Guide to the Plants of Lord Howe Island.* The author, Lord Howe Island.

Hutton, I. (2010b) *A Field Guide to the Ferns of Lord Howe Island.* The author, Lord Howe Island.

Keith, D. A. (2004) *From Ocean Shores to Desert Dunes: The Vegetation of New South Wales and the ACT.* Department of Environment and Conservation, Sydney.

Le Cussan, J. (2006) Eradication of invasive alien plants on Lord Howe Island, NSW using three *Asparagus* species (*Asparagus asparagoides* (L.) Druce, *A. plumosus* Baker and *A. aethiopicus* L.) as case studies. *Plant Protection Quarterly* 21(3): 117-121.

LHIB (2002) *Draft Review of the Permanent Park Preserve Plan of Management.* Report to the Lord Howe Island Board.

LHIB (2006) *Lord Howe Island Weed Management Strategy 2006*. Lord Howe Island Board.

LHIB (2009) *Draft Lord Howe Island Rodent Eradication Plan.* Lord Howe Island Board.

LHIB (2014) *Lord Howe Island Plant Importation Strategy*. Lord Howe Island Board.

LHIB (2015) *Myrtle Rust and Phytophthora Prevention: Protecting Paradise.* Lord Howe Island Board. [Brochure]

LHIB (2016a) *Lord Howe Island Weed Eradication Program Results 2004 – 2014*. Lord Howe Island Board.

LHIB (2016b) *Draft Lord Howe Island Weed Management Strategy 2016–2026*. Lord Howe Island Board.

LHIREP (2019) *Lord Howe Island Rodent Eradication Project Newsletter updates August – December 2019*. Available online at https://lhirodenteradicationproject.org/news-updates/.

Makinson, R.O. (2018) Myrtle Rust reviewed: the impacts of the invasive pathogen *Austropuccinia psidii* on the Australian environment. Plant Biosecurity Cooperative Research Centre, Canberra.

NSW Scientific Committee (2010) *Solanum bauerianum – species presumed extinct listing.* NSW Scientific Committee Final Determination. Available at http://www.environment.nsw.gov.au/determinations/solanumbauerianumFD.htm (Verified Feb 2020).

Pickard, J. (1974) *Vegetation Map (in colour) and notes*. Appendix C, pages 27–36 (+ enclosed map) **In** Recher, H. F and Clarke, S. S. (Eds). *Environmental Survey of Lord Howe Island.* A report to the Lord Howe Island Board. The Australian Museum, Department of Environmental Studies, Sydney.

Pickard, J. (1978) Vegetation of Lord Howe Island. MSc thesis, Department of Botany, University of Sydney.

Pickard, J. (1982) Catastrophic disturbance and vegetation on Little Slope, Lord Howe Island. *Australian Journal of Ecology* **7 (2)**: 169–178.

Pickard, J. (1983) Vegetation of Lord Howe Island. *Cunninghamia* **1(2)**: 133–265.

Pickard, J. (1983a) Rare or threatened vascular plants of Lord Howe Island. *Biological Conservation* **27 (2)**: 125–139.

Pickard, J. (1984) Exotic Plants on Lord Howe Island: Distribution in Space and Time, 1853-1981. *Journal of Biogeography* **11 (3)**: 181–208.

PlantNET (2019) *The NSW Plant Information Network System.* Royal Botanic Gardens and Domain Trust, Sydney. Available at http://plantnet.rbgsyd.nsw.gov.au [Accessed June 2019].

Recher, H. F and Clarke, S. S. (Eds) (1974) *Environmental Survey of Lord Howe Island.* A report to the Lord Howe Island Board. The Australian Museum, Department of Environmental Studies, Sydney.

Rodd, A. N. and Pickard, J. (1983) Census of vascular flora of Lord Howe Island. *Cunninghamia* **1 (2)**: 267–280.

Walker, J. and Hopkins, M. S. (1990) Vegetation. Pages 58–86 **In** McDonald, R. C., Isbell, R. F., Speight, J. G., Walker, J. and Hopkins, M. S. (Eds) *Australian Soil and Land Survey Field Handbook.* 2nd edition. Inkata Press, Melbourne.

Manuscript accepted 19 February 2020

Appendix 1- Plant Community Descriptions

Detailed profiles of each LHIG vegetation community sampled and recognised in this study, and for which there were floristic and physiognomic data, have been prepared to assist in the identification of the vegetation types in the field, particularly for environmental planning.

Each profile is structured as follows.

Vegetation Formation — Vegetation Class:

> **Vegetation Formation** is the broad vegetation group described in Keith (2004) and distinguished by structural (height, cover, strata) and physiognomic (growth forms, leaf types) characteristics. Examples include Rainforests, Grasslands and Heathlands.
>
> **Vegetation Class** is a finer grouping described in Keith (2004) and which identifies floristically related groups within each Vegetation Formation. Examples include Oceanic Rainforests, Maritime Grasslands and Coastal Headland Heaths.

Community: The community number and a concise name of the community, which may include some details of floristics, structure, distribution and habitat. Common plant names, rather than scientific nomenclature, are used in this name. The community number and community name are also the mapping unit number (and code) and mapping unit name.

Scientific name: A more complete description of the floristics of the community. It includes scientific names of dominant or characteristic species in each vegetation stratum, commencing with the tallest stratum. Names within each stratum are separated by a dash, and each stratum is separated by a forward slash. (Note that the database uses hyphens between names within strata.)

Equivalent vegetation types: Lists equivalency to other vegetation classifications, mainly Pickard (1983) and DECC (2007).

Community photographs: An image or images of the community is provided, where possible. Photographs are usually taken at a floristic site or in close proximity to a floristic site. Images of variants of vegetation communities are also provided where possible.

Structure: Provides the vegetation structural type, in accordance with the structural classification of Walker and Hopkins (1990).

Description: Summarises the structure and floristic composition of the vegetation community. Includes information collected about each community during API and field surveys.

Habitat: Describes where the community occurs in terms of elevation, terrain, geology, soils, exposure, moisture, and other environmental characteristics.

Sample sites: Lists all full floristic sites sampled within this vegetation community during the current survey. Communities 20, 21 and 22, which were delineated by the canopy-only analysis, are represented by rapid floristic sites only.

Floristic Group: Lists the PATN analysis floristic group that the community represents. Applies to those groups recognised in either the full floristic or canopy-only analyses.

Mean number of native species per plot: Calculated for communities with full-floristic site data only; presented plus or minus one standard deviation (although only the mean is given where only one full-floristic site was sampled for the community).

Indicator native species: Summarises the diagnostic, or indicator, species that characterise the vegetation community. These are identified by fidelity analysis for communities with full floristic site data, or from field observations where such data do not exist (see 'Fidelity table' below).

Number of exotic species recorded in plots: Listed only for communities for which full-floristic data are available.

Common exotic species: Lists dominant or widespread exotic species, based upon site-based floristic data and field observations.

Threatened species: Identifies flora species that are listed as threatened under the NSW *Biodiversity Conservation Act 2016* (*BC Act*) or the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*) that are known to occur within the vegetation community.

Disturbance and condition: Describes the general condition of the community and notes locations and causes of disturbance.

Areal extent: Total extent of community mapped in this study (in hectares) and extent as a percentage of the total area of the LHIG that was *mapped* in this study.

Areal extent and % of type in PPP: Total extent (in hectares) and the proportion of the community within the Permanent Park Preserve (PPP), excluding Balls Pyramid. The PPP covers all the LHIG outside of the Settlement area (Figure 1) and was formally gazetted in 1982 in order to protect native flora and fauna.

Conservation significance and threats: Identifies the habitat value of the community for threatened fauna, lists current threats, and may provide information regarding the ecological role of the community.

Fidelity tables: These tables provide the output of the fidelity analysis (Bedward 1999) of recognised floristic groups (communities) for which full floristic information was available. The tables identify for each species:

- Group score: The median (i.e. 50th percentile) cover-abundance score of the species in the floristic group.
- Group frequency: The proportion of floristic sites assigned to the floristic group that the species occurs in, e.g. 1 = species recorded in 100% of sites, 0.25 = species recorded in 25% of sites.
- Non-group score: The median (i.e. 50th percentile) cover-abundance score of each species in all other floristic groups.

- Non-group frequency: The proportion of all sites assigned to all other floristic groups in which that species occurs.
- Fidelity class: Positive = the taxon is diagnostic for the floristic group; Negative = taxon is generally absent from the floristic group; Constant = the taxon displays similar frequency and cover across a number of floristic groups; Uninformative = the taxon is insufficiently recorded to provide meaningful analysis. Exotic species are indicated by an asterisk preceding the scientific name.

Grasslands — Maritime Grasslands

Community 1 Coastal Spinifex – Dune Bean – Club Rush – *Melanthera biflora* – Saltwater Couch beach strandline grassland

Scientific name: *Spinifex sericeus – Vigna marina – Ficinia nodosa – Melanthera biflora – Sporobolus virginicus* var. *virginicus*.

Equivalent vegetation types: Coral Sand Beach and Dune (Pickard 1983); Coral Sand Beach and Dune (DECC 2007).

Structure: Mixed, closed, low to tall sod grassland or sedgeland.

Description: This community is usually a low, dense grassland or sedgeland. Scattered emergent shrubs of Bully Bush (*Cassinia tenuifolia*), Red Berrywood (*Ochrosia elliptica*) and Hopwood (*Dodonaea viscosa* subsp. *burmanniana*) may be present. Common ground layer species are Coastal Spinifex (*Spinifex sericeus*), Dune Bean (*Vigna marina*), Club Rush (*Ficinia nodosa*), *Melanthera biflora*, Saltwater Couch (*Sporobolus virginicus* var. *virginicus*), Pigface (*Carpobrotus glaucescens*), *Tylophora biglandulosa*, Beach Morning Glory (*Ipomoea brasiliensis*) and Coastal Jack Bean (*Canavalia rosea*). The tall herb Crinum Lily (*Crinum pedunculatum*) is sometimes present. Weeds such as Kikuyu (*Cenchrus clandestinus*) and Buffalo Grass (*Stenotaphrum secundatum*) are common.

Habitat: Occurs on unconsolidated calcareous beach dunes, such as those at North, Old Settlement, Neds, Blinky and Lagoon Beaches.

Sample sites: (*N* = 8) LHI001, LHI003, LHI005, LHI006, LHI008, LHIFF62, LHIFF85, LHIFF86.

Floristic Group: 1.

Mean number of native species per plot: 7.1 ± 0.7.

Indicator native species: *Spinifex sericeus*, *Vigna marina*, *Ficinia nodosa*, *Melanthera biflora*, *Sporobolus virginicus* var. *virginicus*, *Calystegia soldanella*, *Actites megalocarpus*.

Number of exotic species recorded in plots: 23.

Common exotic species: *Cakile edentula*, *Cenchrus clandestinus*, *Euphorbia paralias*, *Hydrocotyle bonariensis*, *Hypochaeris radicata*, *Lobularia maritima*, *Stenotaphrum secundatum*.

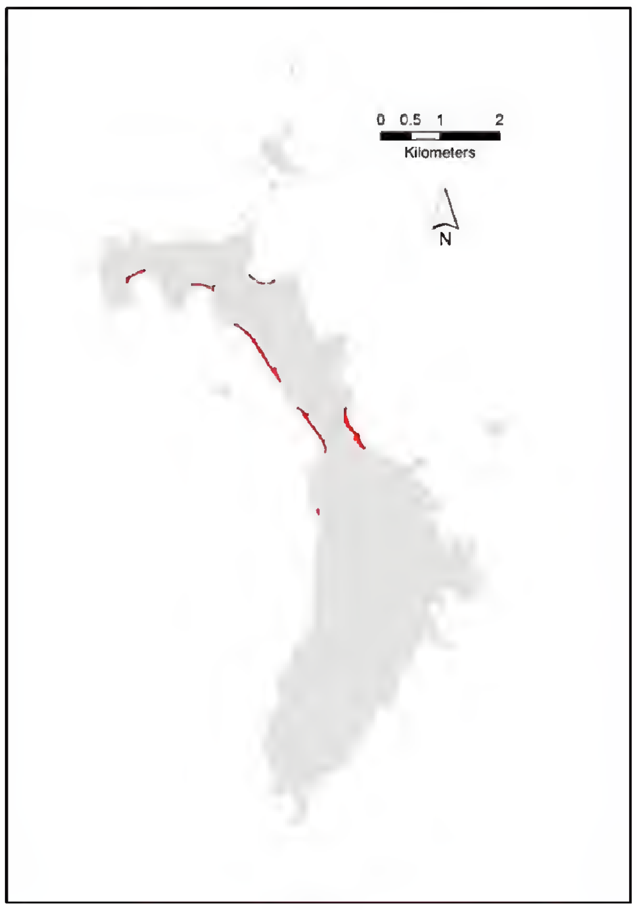
Threatened species: *Chamaesyce psammogeton* (Endangered – *BC Act*).

Disturbance and Condition: Weed disturbance is common in this community and some areas are dominated by weeds, especially Buffalo Grass and Kikuyu.

Areal extent: 9.26 ha (0.62% of mapped area).

Areal extent and proportion in PPP: 1.47 ha (15.86%).

Conservation significance and threats: This community provides habitat for *Chamaesyce psammogeton* and the Lord Howe Island Skink (*Oligosoma lichenigera*). It also provides breeding habitat for Wedge-tailed Shearwaters (*Ardenna pacifica*) and Sooty Terns (*Onychoprion fuscata*). Invasion by weeds is widespread and some areas are highly disturbed by infrastructure (such as boat sheds) and human recreational use. Coastal erosion and recession potentially threatens Lagoon Beach. The Blinky Beach dunes have been significantly modified to facilitate airport operations. This community plays an important role in consolidation of potentially mobile beach dunes.



Key Diagnostic Species Floristic Group 1

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Spinifex sericeus	4	1	1	0.01	positive
Vigna marina	3	1	1	0.04	positive
Ficinia nodosa	3	0.88	2	0.14	positive
Melanthera biflora	3	0.75	3	0.09	positive
Sporobolus virginicus var. *virginicus*	3	0.75	3	0.09	positive
**Cakile edentula*	2	0.88	1	0.01	positive
Ipomoea brasiliensis	2	0.75	2	0.01	positive
Calystegia soldanella	2	0.5	0	0	positive
Cryptocarya triplinervis var. *triplinervis*	0	0	2	0.59	negative
Drypetes deplanchei	0	0	2	0.73	negative
Microsorum pustulatum subsp. *howense*	0	0	2	0.53	negative
Oplismenus imbecillis	0	0	2	0.5	negative
Parsonsia howeana	0	0	2	0.68	negative
Smilax australis	0	0	2	0.60	negative
Carpobrotus glaucescens	3	0.25	2	0.05	uninformative
Tylophora biglandulosa	3	0.25	1	0.04	uninformative

Community 2 *Melanthera biflora* – Saltwater Couch herbland/grassland on coral boulder beaches and rocky headlands

Scientific name: *Melanthera biflora – Sporobolus virginicus* var. *virginicus – Canavalia rosea*.

Equivalent vegetation types: Calcarenite and Coral Boulder Beach; Cliff (Pickard 1983); Calcarenite and Coral Boulder Beach; Cliff (DECC 2007).

Structure: Mixed, low to tall forbland/sod grassland.

Description: A variable coastal community with the ground layer dominated by *Melanthera biflora* or Saltwater Couch (*Sporobolus virginicus* var. *virginicus*). Other common species include Chaff Flower (*Achyranthes aspera*), Coastal Jack Bean (*Canavalia rosea*), Beach Bean (*Ipomoea brasiliensis*), Club Rush (*Ficinia nodosa*), *Tylophora biglandulosa* and Crinum Lily (*Crinum pedunculatum*). A sparse upper layer of emergent shrubs or small trees of Sallywood (*Lagunaria patersonia* subsp. *patersonia*), Kentia Palm (*Howea forsteriana*) and Bully Bush (*Cassinia tenuifolia*) may be present.

Variation: Varies from almost 100% cover on basaltic soil on steep slopes to very low cover among coral or basalt boulders on footslopes or flats behind beaches.

Habitat: Usually occurs on rocky calcarenite flats in near-coastal areas exposed to the ocean, or occasionally on basalt slopes, mainly in the northern half of the island.

Sample sites: (*N* = 4) LHI002, LHI007, LHIFF60, LHIFF67.

Floristic Groups: 2, 3, 7.

Mean number of native species per plot: 7.0 ± 3.2.

Indicator native species: *Melanthera biflora*, *Achyranthes aspera*, *Canavalia rosea*, *Sporobolus virginicus* var. *virginicus*.

Number of exotic species recorded in plots: 10.

Common exotic species: *Ipomoea cairica*, *Melilotus indicus*, *Paspalum dilatatum*, *Plantago lanceolata*, *Cenchrus clandestinus*, *Sonchus oleraceus*, *Taraxacum officinale*, *Vicia sativa*.

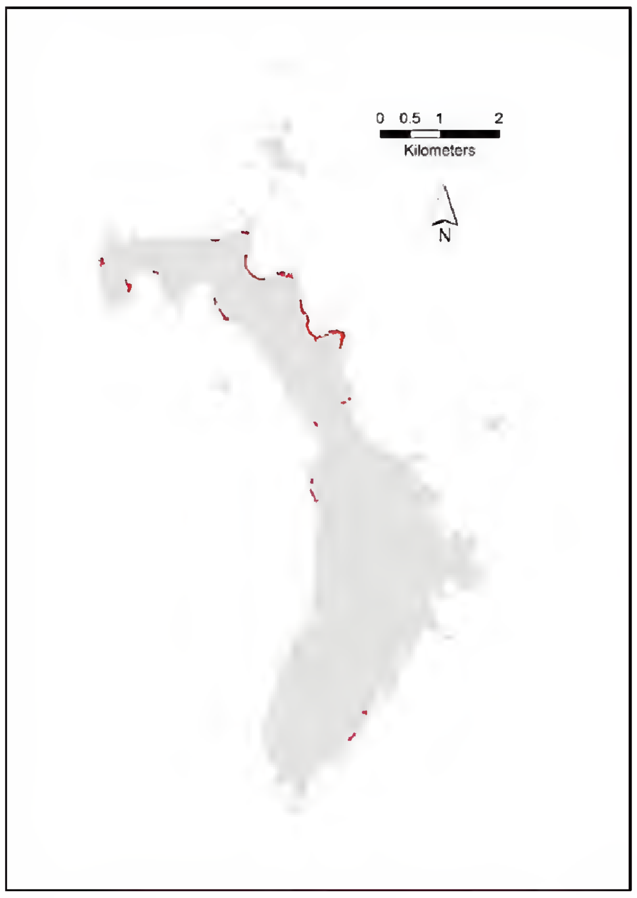
Disturbance and Condition: The condition of this community varies, with some sites dominated by weeds such as Kikuyu (*Cenchrus clandestinus*).

Areal extent: 5.74 ha (0.38% of mapped area).

Areal extent and % of type in PPP: 3.31 ha (57.72%).

Conservation significance and threats: May provide breeding habitat for Black-winged Petrels (*Pterodroma nigripennis*), Sooty Terns (*Onychoprion fuscata*) and Little Shearwaters (*Puffinus assimilis*). Weed invasion is a threat, particularly along low calcarenite headlands between Blinky Beach and Neds Beach.

Key Diagnostic Species Floristic Group 2



Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Melanthera biflora	5	1	2	0.13	positive
Howea forsteriana	3	1	2	0.32	positive
Lagunaria patersonia subsp. *patersonia*	3	1	1	0.29	positive
Achyranthes aspera	3	0.5	2	0.08	positive
Canavalia rosea	3	0.5	2	0.04	positive
Sporobolus virginicus var. *virginicus*	3	0.5	3	0.14	positive
Ficinia nodosa	2	0.5	2	0.22	positive
Ipomoea brasiliensis	2	0.5	2	0.07	positive
Microsorum pustulatum subsp. *howense*	2	0.5	2	0.48	positive
**Sonchus oleraceus*	2	0.5	1	0.11	positive
**Taraxacum officinale*	2	0.5	0	0	positive

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Parsonsia howeana	3	1	2	0.61	constant

Key Diagnostic Species Floristic Group 3

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Melanthera biflora	5	1	3	0.14	positive
**Paspalum dilatatum*	3	1	2	0.01	positive
Achyranthes aspera	2	1	3	0.08	positive
Canavalia rosea	2	1	3	0.04	positive
**Chloris gayana*	2	1	0	0	positive
**Ipomoea cairica*	2	1	1	0.24	positive
**Cenchrus clandestinus*	2	1	3	0.05	positive
Stephania japonica var. *timoriensis*	2	1	1	0.27	positive

Key Diagnostic Species Floristic Group 7

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
**Cenchrus clandestinus*	5	1	3	0.05	positive
Canavalia rosea	3	1	2	0.04	positive
Cryptocarya triplinervis var. *triplinervis*	0	0	2	0.54	negative
Drypetes deplanchei	0	0	2	0.67	negative
Parsonsia howeana	0	0	2	0.62	negative
Smilax australis	0	0	2	0.55	negative

Heathlands — Coastal Headland Heaths

Community 3 Grey Saltbush shrubland of exposed talus slopes

Scientific name: *Atriplex cinerea – Myoporum insulare / Sporobolus virginicus – Achyranthes aspera – Melanthera biflora*.

Equivalent vegetation types: *Atriplex cinerea* Orthophyll Dwarf Scrub (Pickard 1983); Saltbush (*Atriplex cinerea*) Dwarf Scrub (DECC 2007).

Structure: Mid-high to tall chenopod shrubland.

Description: A shrubland community dominated by Grey Saltbush (*Atriplex cinerea*), with Juniper (*Myoporum insulare*) also occurring in the shrub layer. Common species in the ground layer include *Melanthera biflora*, Saltwater Couch (*Sporobolus virginicus* var. *virginicus*) and Chaff Flower (*Achyranthes aspera*). *Lepidium howei-insulae* and Sea Celery (*Apium prostratum* subsp. *howense*) are present in this community but are uncommon in other floristic groups.

Habitat: On steep slopes of talus debris below sea-cliffs, usually with a thin layer of coral sand over basalt or tuff. Restricted to the sea-cliffs of Malabar, and between Neds Beach and Middle Beach.

Sample sites: (N = 1) LHIFF70; this is a locality below Malabar and difficult to access.

Floristic Group: 4.

Mean number of native species per plot: 8.

Indicator native species: *Atriplex cinerea*, *Myoporum insulare*.

Number of exotic species recorded in plots: 0.

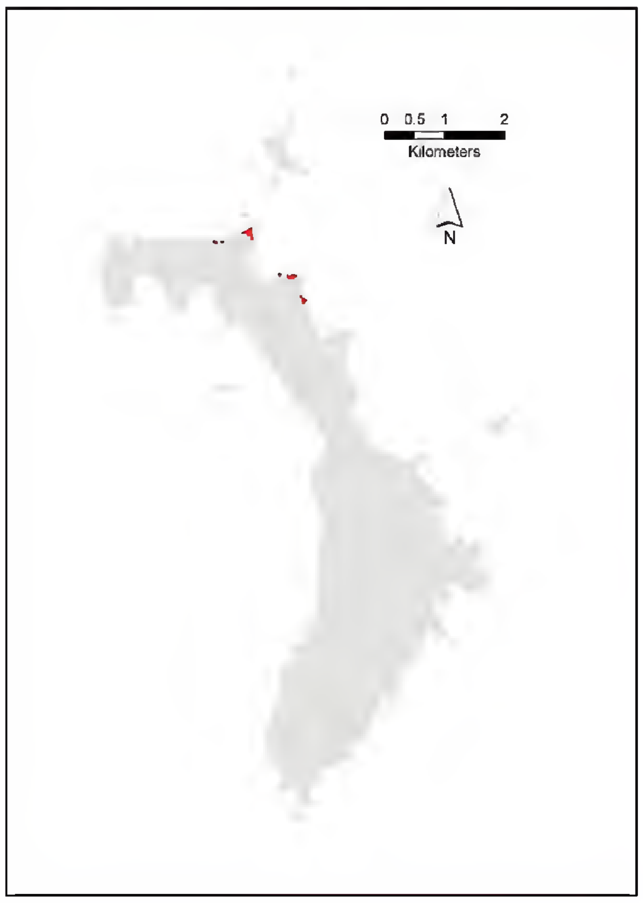
Common exotic species: *Cenchrus clandestinus*, *Stenotaphrum secundatum*.

Disturbance and Condition: Occurrences below Malabar and at Searles Point are in good condition, but there is some Kikuyu (*Cenchrus clandestinus*) and Buffalo Grass (*Stenotaphrum secundatum*) in occurrences near Neds Beach.

Areal extent: 0.92 ha (0.06% of mapped area).

Areal extent and % of type in PPP: 0.55 ha (59.31%).

Conservation significance and threats: This is a very restricted plant community on LHI that could be threatened by stochastic events, such as major storms, and weed invasion.



Key Diagnostic Species Floristic Group 4

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Atriplex cinerea	5	1	0	0	positive
Achyranthes aspera	2	1	3	0.08	positive
Melanthera biflora	2	1	3	0.14	positive
Myoporum insulare	2	1	1	0.12	positive

Grasslands — Maritime Grasslands

Community 4 Chaff Flower – Ice Plant – Saltwater Couch – Pigface herbland/grassland of rock shelves and cliffs

Scientific name: *Achyranthes aspera* – *Sesuvium portulacastrum* – *Sporobolus virginicus* var. *virginicus* – *Carpobrotus glaucescens*.

Equivalent vegetation types: *Ipomoea cairica* – *Carpobrotus glaucescens* Evergreen Broad-leaved Weedy Vegetation; part of Cliffs (Pickard 1983); *Ipomoea cairica* – *Carpobrotus glaucescens* Herbland; part of Cliff (DECC 2007).

Structure: Low to mid-high mixed herbland or sod grassland.

Description: A herbland/grassland community of exposed rocky coastal sites in which Chaff Flower (*Achyranthes aspera*), Ice Plant (*Sesuvium portulacastrum*) and Saltwater Couch (*Sporobolus virginicus* var. *virginicus*) variously dominate. Pigface (*Carpobrotus glaucescens*), New Zealand Spinach (*Tetragonia tetragonioides*) and *Melanthera biflora* are also common. Occasional stunted emergent Cotton Wood (*Celtis conferta* subsp. *amblyphylla*), Tea Tree (*Melaleuca howeana*) or Greybark (*Drypetes deplanchei*) may occur. The introduced Five-leaf Morning Glory (*Ipomoea cairica*) is common in some areas.

Variation: Each of the dominants may form pure stands at the local scale.

Habitat: Occurs on exposed rocky sites near the ocean, on basalt, breccia and tuff, as well as calcarenite rock shelves. Main area of occurrence is the sea-cliffs and rock shelves of the northern hills, Hells Gates and Mutton Bird, Roach, and Tenth of June Islands.

Sample sites: ($N = 2$) LHI004, LHIFF80.

Floristic Group: 5.

Mean number of native species per plot: 9.0 ± 0.0.

Indicator native species: *Sesuvium portulacastrum*, *Achyranthes aspera, Carpobrotus glaucescens*, *Tetragonia tetragonioides*, *Sporobolus virginicus* var. *virginicus*, *Apium prostratum* subsp. *howense*, *Portulaca oleracea*, *Senecio howeanus*.

Number of exotic species recorded in plots: 6.

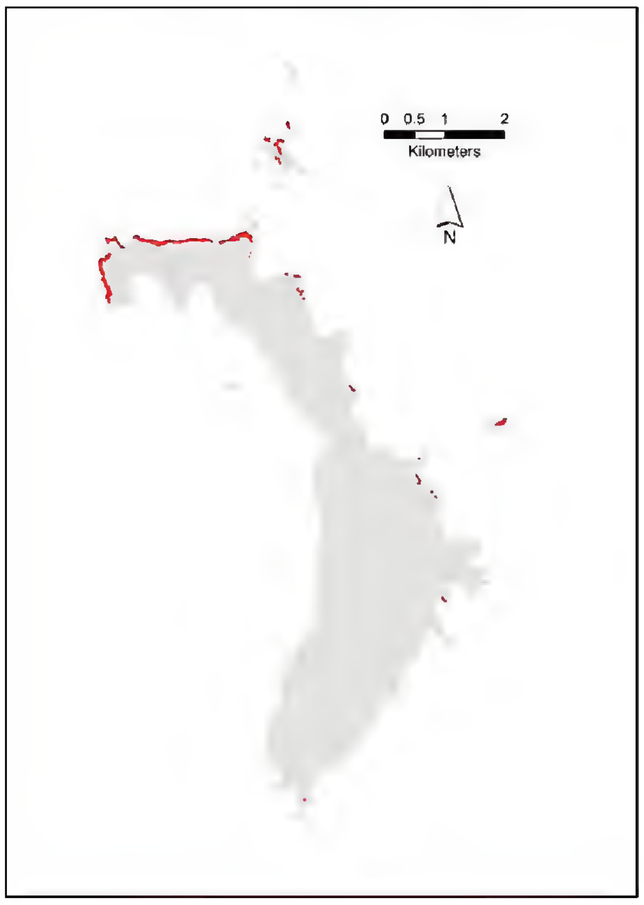
Common exotic species: *Ipomoea cairica*, *Parietaria debilis*, *Sonchus oleraceus*.

Disturbance and Condition: Generally in good condition with some minor weed infestations.

Areal extent: 13.94 ha (0.93% of mapped area).

Areal extent and % of type in PPP: 13.25 ha (95.08%).

Conservation significance and threats: Provides nesting habitat for a number of seabird species, particularly on Roach Island. Some occurrences may be threatened by extreme storm events, sea-level rise and degradation by weed invasion (particularly *Ipomoea cairica*).



Key Diagnostic Species Floristic Group 5

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Achyranthes aspera	4	1	2	0.07	positive
Sesuvium portulacastrum	4	1	0	0	positive
Sporobolus virginicus var. *virginicus*	4	1	3	0.13	positive
Carpobrotus glaucescens	3	1	2	0.05	positive
Melanthera biflora	3	1	3	0.13	positive
Tetragonia tetragonioides	3	1	2	0.05	positive
Apium prostratum subsp. *howense*	2	1	1	0.01	positive
Portulaca oleracea	2	0.5	0	0	positive
Senecio howeanus	1	0.5	0	0	positive

Heathlands — Coastal Headland Heaths

Community 5 Tea Tree shrubland on exposed rocky slopes

Scientific name: *Melaleuca howeana / Achyranthes aspera / Sporobolus virginicus* var. *virginicus – Poa poiformis*.

Equivalent vegetation types: *Melaleuca howeana* Straight Narrow Sclerophyll Scrub (Pickard 1983); *Melaleuca howeana* Closed Scrub (DECC 2007).

Structure: Closed to open, tall to very tall shrubland.

Description: A shrubland dominated by Tea Tree (*Melaleuca howeana*), with occasional emergent Curly Palm (*Howea belmoreana*) and Sallywood (*Lagunaria patersonia* subsp. *patersonia*). Other shrub species present include Juniper (*Myoporum insulare*), Bully Bush (*Cassinia tenuifolia*) and Christmas Bush (*Alyxia ruscifolia*). The vines *Parsonsia howeana* and *Muehlenbeckia complexa* may be present. The ground layer is usually sparse under dense shrubs, or dense in more open sites. Common species include Chaff Flower (*Achyranthes aspera*), Saltwater Couch (*Sporobolus virginicus* var *virginicus*), Pigface (*Carpobrotus glaucescens*), *Melanthera biflora*, Club Rush (*Ficinia nodosa*), *Poa poiformis*, *Oplismenus imbecillis* and New Zealand Spinach (*Tetragonia tetragonioides*).

Habitat: Occurs on steep rocky slopes, exposed cliff tops, regenerating landslips, rock outcrops, ridge lines, and rocky foreshores of bays. Usually occurs between sea level and 150 m altitude but occasionally higher.

Sample sites: (*N* = 3) LHIFF03, LHIFF005, LHIFF07.

Floristic Groups: 6, 11.

Mean number of native species per plot: 11.7 ± 7.2.

Indicator native species: *Melaleuca howeana*, *Achyranthes aspera*.

Number of exotic species recorded in plots: 11.

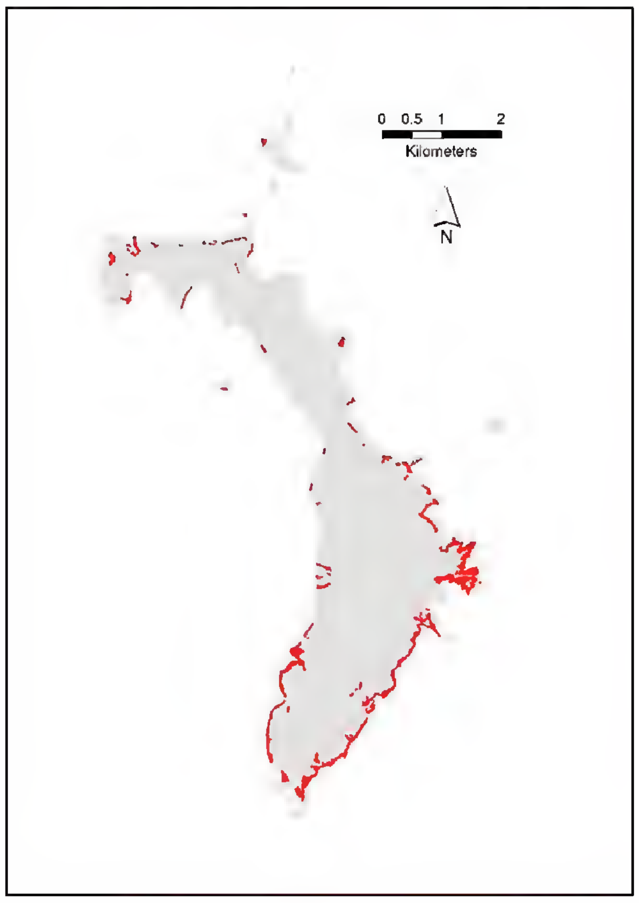
Common exotic species: *Bromus catharticus*, *Chenopodium murale*, *Ipomoea cairica*.

Disturbance and Condition: Generally in good condition except for stochastic disturbance such as landslips (Pickard 1982), and localised weed incursions.

Areal extent: 60.6 ha (4.03% of mapped area).

Areal extent and % of type in PPP: 59 ha (97.37%).

Conservation significance and threats: Provides nesting habitat for Sooty Terns (*Onychoprion fuscata*), Common Noddies (*Anous stolidus*), Black-winged Petrels (*Pterodroma nigripennis*) and Little Shearwaters (*Puffinus assimilis*).



Key Diagnostic Species Floristic Group 6

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
**Bromus catharticus*	4	1	2	0.01	positive
Melaleuca howeana	4	1	2	0.10	positive
Achyranthes aspera	3	1	3	0.07	positive
**Chenopodium murale*	3	1	1	0.02	positive
**Ipomoea cairica*	3	0.5	1	0.23	positive
Carpobrotus glaucescens	2	1	3	0.05	positive
Commelina cyanea	2	0.5	1	0.26	positive
Cotula australis	2	0.5	1	0.01	positive
Ficinia nodosa	2	0.5	2	0.20	positive
Microlaena stipoides var. *stipoides*	2	0.5	0	0	positive
Nicotiana forsteri	2	0.5	0	0	positive
Cenchrus clandestinus	2	0.5	3	0.05	positive

Scientific name	**Group score**	**Group frequency**	**Non-group score**	**Non-group frequency**	**Fidelity class**
Poa poiformis var. *poiformis*	2	0.5	1	0.11	positive
Sporobolus virginicus var. *virginicus*	2	0.5	3	0.14	positive
Tetragonia tetragonioides	2	1	2	0.05	positive

Key Diagnostic Species Floristic Group 11

Scientific name	**Group score**	**Group frequency**	**Non-group score**	**Non-group frequency**	**Fidelity class**
Melaleuca howeana	4	1	2	0.11	positive
Myoporum insulare	3	1	1	0.13	positive
Alyxia ruscifolia	2	1	1	0.42	positive
Lagunaria patersonia subsp. *patersonia*	2	1	1	0.29	positive
Myrsine platystigma	2	1	1	0.32	positive
Oplismenus imbecillis	2	1	2	0.45	positive
Pandorea pandorana subsp. *austrocaledonica*	2	1	1	0.45	positive
Solanum nigrum	2	1	1	0.12	positive
Parsonsia howeana	3	1	2	0.61	constant
Drypetes deplanchei	2	1	2	0.66	constant

Forested Wetlands — Coastal Swamp Forests

Community 6 Sallywood swamp forest of poorly drained, low-lying areas

Scientific name: *Lagunaria patersonia* subsp. *patersonia / Aegiceras corniculata – Hibiscus tiliaceus – Myoporum insulare / Commelina cyanea.*

Equivalent vegetation types: *Lagunaria patersonia* Broad Orthophyll Sclerophyll Forest (Pickard 1983); Sallywood *Lagunaria patersonia* Closed Swamp Forest (DECC 2007).

Structure: A mid-high to tall closed to open forest.

Description: This community is dominated by Sallywood (*Lagunaria patersonia* subsp. *patersonia*) with occasional Cottonwood Hibiscus (*Hibiscus tiliaceus*) and Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*). A sparse mid-layer of River Mangrove (*Aegiceras corniculata*) or Juniper (*Myoporum insulare*), or both, is usually present. The ground layer varies from dense to sparse, and common species are Blue Wandering Jew (*Commelina cyanea*) and Kikuyu (*Cenchrus clandestinus*).

Variation: Some of the small areas mapped as this community are recently revegetated sites.

Habitat: Restricted to areas of moist alluvium along Soldiers Creek, Cobbys Corner near the Golf Course, Pinetrees, Settlement Creek and behind North Beach. Most examples of this community are regenerating, and adult trees are showing signs of dieback. A large area of this community was lost during construction of the airport (Pickard 1983).

Sample sites: (*N* = 1) LHIFF37.

Floristic Group: 8.

Mean number of native species per plot: 5.

Indicator native species: *Lagunaria patersonia* subsp. *patersonia*, *Aegiceras corniculatum*, *Hibiscus tiliaceus*, *Commelina cyanea*, *Triglochin striata*.

Number of exotic species recorded in plots: 3.

Common exotic species: *Cenchrus clandestinus, Stenotaphrum secundatum*.

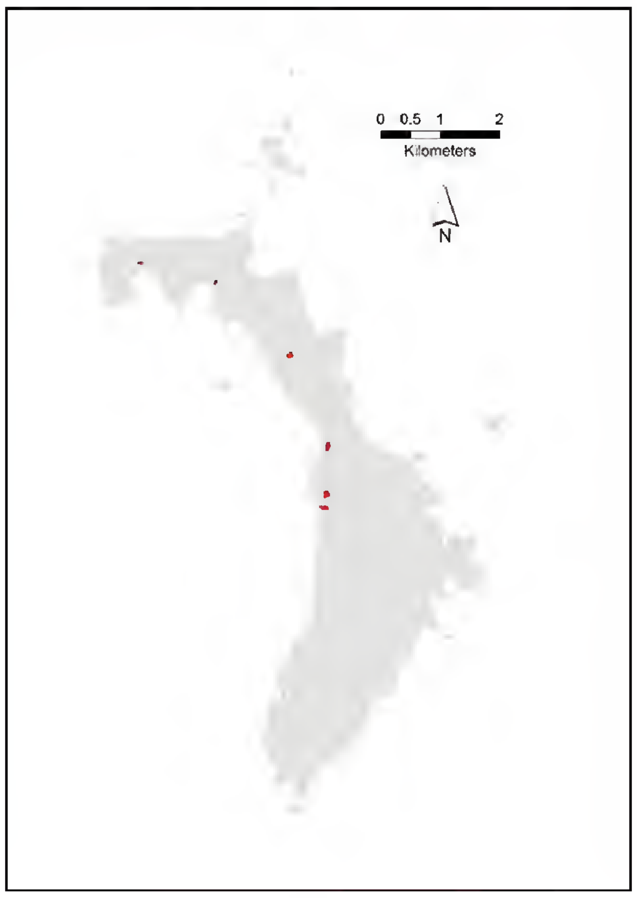
Disturbance and Condition: The few remnants of this community are disturbed and in poor condition.

Areal extent: 0.89 ha (0.06% of mapped area).

Areal extent and % of type in PPP: 0.04 ha (4.33%).

Conservation significance and threats: A highly restricted community that continues to be degraded by weeds, grazing and exposure. It is also threatened by mechanical opening of creek lines during potential flooding events. Even before European settlement this community would have occupied only a small area, and most has been cleared, as it occurs on flat, relatively fertile sites.

Endangered Ecological Community: *Lagunaria* Swamp Forest on Lord Howe Island (Critically Endangered Ecological Community).



Key Diagnostic Species Floristic Group 8

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Commelina cyanea	6	1	1	0.26	positive
Aegiceras corniculatum	3	1	1	0.01	positive
Lagunaria patersonia subsp. *patersonia*	3	1	1	0.29	positive
**Stenotaphrum secundatum*	2	1	4	0.07	positive
**Araucaria heterophylla*	1	1	0	0	positive
**Aster subulatus*	1	1	0	0	positive
Triglochin striata	1	1	0	0	positive

Saline Wetlands — Saltmarshes

Community 7 Saltwater Couch saltmarsh of poorly drained, brackish flats

Scientific name: *Avicennia marina* subsp. *australasica* / *Sporobolus virginicus*.

Equivalent vegetation types: Part of *Avicennia marina* subsp. *australasica* Broad Sclerophyll Swamp Scrub; part of *Aegiceras corniculatum* Broad Sclerophyll Swamp Scrub (Pickard 1983); part of Mangrove (*Avicennia marina* var. *australasica*) Open Swamp Scrub; part of Mangrove *Aegiceras corniculatum* Closed Swamp Scrub (DECC 2007).

Structure: Low closed sod grassland.

Description: Scattered emergent shrubs of Grey Mangrove (*Avicennia marina* subsp. *australasica*), River Mangrove (*Aegiceras corniculatum*) or *Hibiscus tiliaceus* may occur in this community. The ground layer is dominated by a dense cover of Saltwater Couch (*Sporobolus virginicus* var. *virginicus*), with occasional Crinum Lily (*Crinum pedunculatum*).

Habitat: Occurs along a small creek line growing in alluvium and mud that is rarely influenced by saltwater incursion. Located only at Settlement Creek.

Sample sites: (*N* = 1) FF71.

Floristic Group: 9.

Mean number of native species per plot: 10.

Indicator native species: *Sporobolus virginicus* var. *virginicus*, *Hibiscus tiliaceus*, *Avicennia marina* subsp. *australasica*.

Number of exotic species recorded in plots: 1.

Common exotic species: *Stenotaphrum secundatum*.

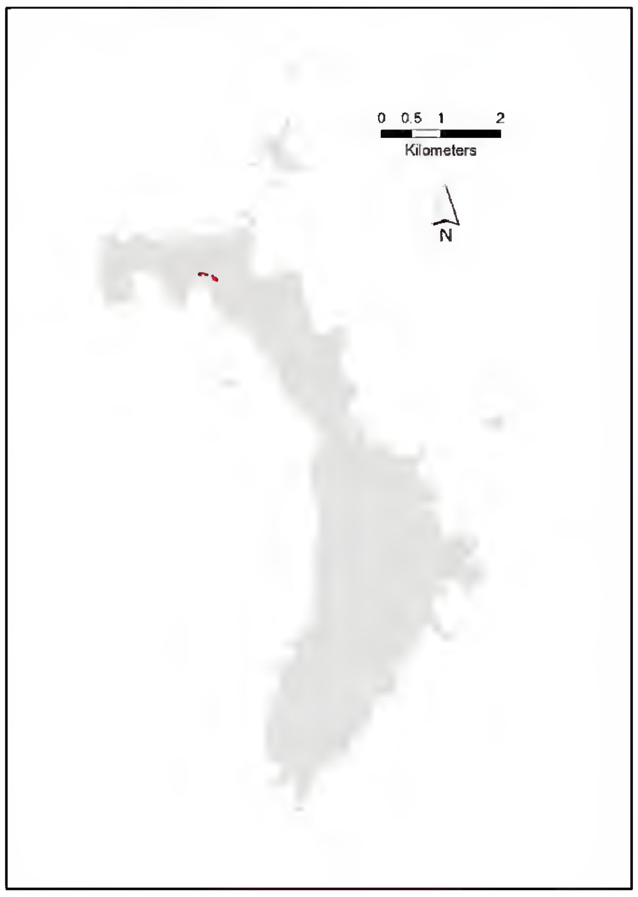
Disturbance and Condition: The small examples of this community are in reasonable condition as they occur in a fenced-off area of assisted native regeneration.

Areal extent: 0.3 ha (0.02% of mapped area).

Areal extent and % of type in PPP: 0 ha (0%).

Conservation significance and threats: A highly restricted community in a specialised habitat. It may be threatened by mechanical opening of creek lines during potential flooding events. It could be replaced by mangrove or Sallywood (*Lagunaria patersonia* subsp. *patersonia*) communities over time.

Endangered Ecological Community: Floristically equivalent to Coastal Saltmarsh in the NSW North Coast, Sydney Basin and South East Corner Bioregion.



Key Diagnostic Species Floristic Group 9

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Sporobolus virginicus var. *virginicus*	5	1	3	0.14	positive
Avicennia marina subsp. *australasica*	2	1	0	0	positive
Hibiscus tiliaceus	1	1	0	0	positive

Heathlands — Coastal Headland Heaths

Community 8 Bully Bush – Hopwood shrubland on shallow rocky soils

Scientific name: *Lagunaria patersonia* subsp. *patersonia* – *Drypetes deplanchei* / *Cassinia tenuifolia* – *Dodonaea viscosa* subsp. *burmanniana* – *Melaleuca howeana* / *Muehlenbeckia complexa* / *Ficinia nodosa* – *Sporobolus virginicus* var. *virginicus* – *Poa poiformis*.

Equivalent vegetation types: *Cassinia tenuifolia* Straight Narrow Sclerophyll Scrub; *Dodonaea viscosa* Evergreen Broad Sclerophyll Scrub (Pickard 1983); Bully Bush (*Cassinia tenuifolia*) Closed Scrub; *Dodonaea viscosa* Closed Scrub (DECC 2007).

Structure: Mid-high to tall closed to open shrubland.

Description: A shrubland community with a sparse, emergent upper layer of Greybark (*Drypetes deplanchei*) and Sallywood (*Lagunaria patersonia* subsp. *patersonia*) often present. There is an open to dense shrub layer dominated by Bully Bush (*Cassinia tenuifolia*) or Hopwood (*Dodonaea viscosa* subsp. *burmanniana*), or both, with occasional Tea Tree (*Melaleuca howeana*). The vines *Muehlenbeckia complexa* and Boat Vine (*Pandorea pandorana* subsp. *austrocaledonica*) are common in the mid- and ground layers, the latter including Saltwater Couch (*Sporobolus virginicus* var. *virginicus*), *Poa poiformis*, Leafy Flat Sedge (*Cyperus lucidus*) and Club Rush (*Ficinia nodosa*).

Variation: The two floristic groups included in this community differ, with Group 10 being shrubbier and weedier than Group 13, which has more Saltwater Couch and Club Rush, and fewer weeds. Some areas may represent regeneration from previous clearing for grazing, and may, in time, transform into Greybark – Blackbutt rainforest.

Habitat: Located on steep slopes below cliffs, rocky ridges and regenerating landslips with shallow soils derived from basalt and breccia.

Sample sites: (*N* = 4) LHIFF001, LHIFF02, LHIFF04, LHIFF077.

Floristic Groups: 10, 13.

Mean number of native species per plot: 14 ± 4.2.

Indicator native species: *Cassinia tenuifolia*, *Dodonaea viscosa* subsp. *burmanniana*, *Muehlenbeckia complexa*, *Pandorea pandorana* subsp. *austrocaledonica*.

Number of exotic species recorded in plots: 12.

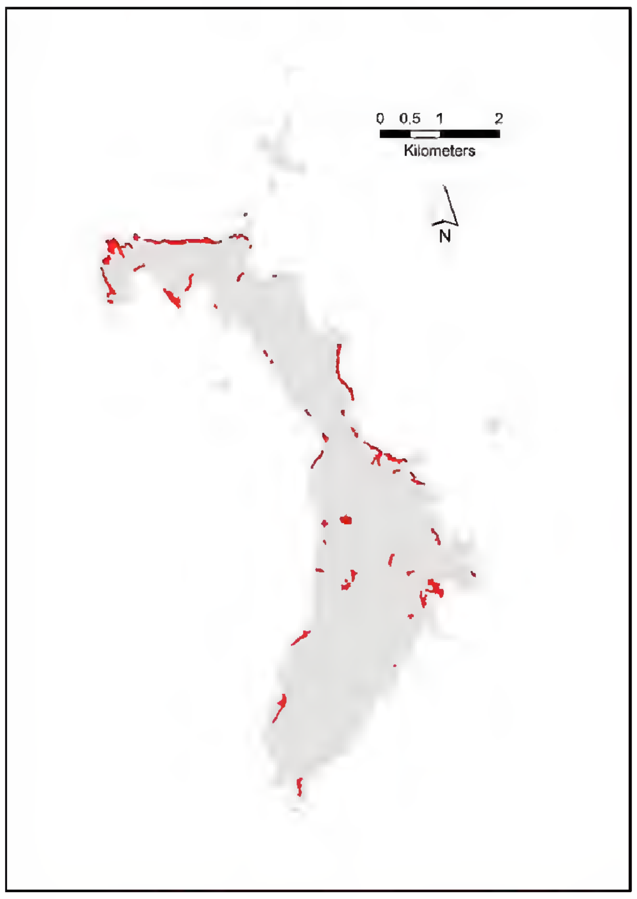
Common exotic species: *Bidens pilosa*, *Lilium formosanum*, *Sporobolus africanus*.

Disturbance and Condition: Generally in good condition, although some sites, particularly on recent landslips, can be weedy. This community was sometimes severely affected by goats in the past.

Areal extent: 37.38 ha (2.49% of mapped area).

Areal extent and % of type in PPP: 34.73 ha (92.91%).

Conservation significance and threats: This community is an important coloniser of disturbed sites, such as landslips (Pickard 1982). Provides nesting habitat for Sooty Terns (*Onychoprion fuscata*), Common Noddies (*Anous stolidus*) and Black-winged Petrels (*Pterodroma nigripennis*).



Key Diagnostic Species Floristic Group 10

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Cassinia tenuifolia	3	1	1	0.24	positive
Dodonaea viscosa subsp. *burmanniana*	3	1	1	0.32	positive
Muehlenbeckia complexa	3	1	2	0.11	positive
Pandorea pandorana subsp. *austrocaledonica*	3	1	1	0.44	positive

Scientific name	**Group score**	**Group frequency**	**Non-group score**	**Non-group frequency**	**Fidelity class**
**Sporobolus africanus*	3	0.5	2	0.02	positive
Lagunaria patersonia subsp. *patersonia*	2	1	2	0.29	positive
Oxalis rubens	2	1	1	0.04	positive
Pimelea congesta	2	0.5	2	0.05	positive
Poa poiformis var. *poiformis*	2	0.5	1	0.11	positive
**Cyclospermum leptophyllum*	1	0.5	0	0	positive
**Cynodon dactylon*	1	0.5	0	0	positive
**Parietaria judaica*	1	0.5	0	0	positive
**Torilis nodosa*	1	0.5	0	0	positive
Drypetes deplanchei	3	0.5	2	0.67	constant
Parsonsia howeana	2	1	2	0.61	constant

Key Diagnostic Species Floristic Group 13

Scientific name	**Group score**	**Group frequency**	**Non-group score**	**Non-group frequency**	**Fidelity class**
Cassinia tenuifolia	4	1	1	0.24	positive
Ficinia nodosa	3	1	2	0.19	positive
Sporobolus virginicus var. *virginicus*	3	0.5	3	0.14	positive
Lagunaria patersonia subsp. *patersonia*	2	1	2	0.29	positive
Melaleuca howeana	2	1	2	0.10	positive
Melanthera biflora	2	0.5	3	0.14	positive
Drypetes deplanchei	2	1	2	0.65	constant

Grasslands — Maritime Grasslands

Community 9 Common Reed – Leafy Flat Sedge – Couch grassland or sedgeland of northern hills and offshore islands

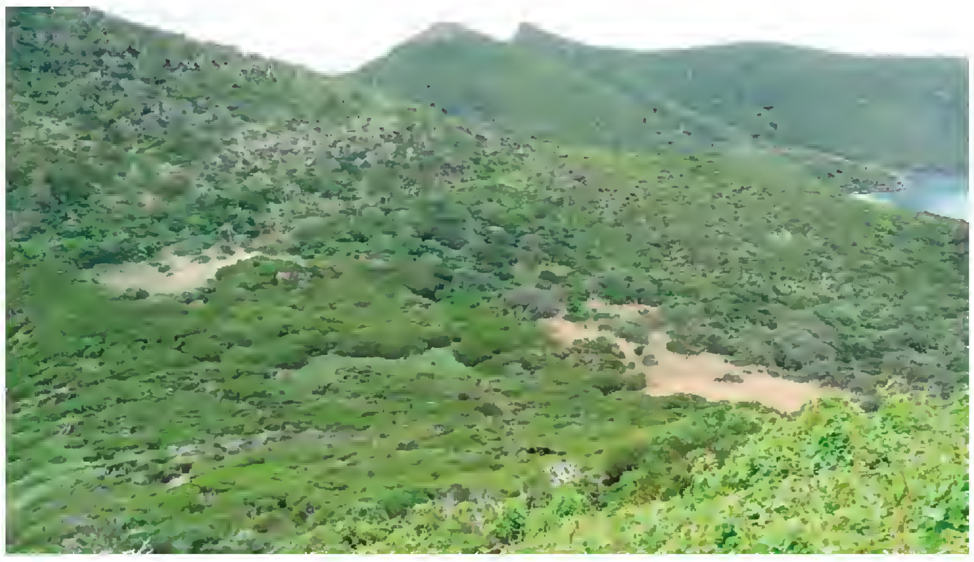
Scientific name: *Phragmites australis – Cyperus lucidus – Cynodon dactylon*.

Equivalent vegetation types: *Cyperus lucidus* Sclerophyll Tall Grass (Pickard 1983); *Cyperus lucidus* Sedgeland (DECC 2007).

Structure: Closed low to very tall grassland, or mid-high to tall sedgeland.

Description: Includes a variety of sedgelands and grasslands dominated by Common Reed (*Phragmites australis*), Leafy Flat Sedge (*Cyperus lucidus*) or Couch (*Cynodon dactylon*). Emergent Sallywood (*Lagunaria patersonia* subsp. *patersonia*) and Tea Tree (*Melaleuca howeana*) are sometimes present. The vines *Parsonsia howeana* and *Muehlenbeckia complexa* occur with Common Reed, and the tall herb Crinum Lily (*Crinum pedunculatum*) is sometimes present. Other ground layer species include Saltwater Couch (*Sporobolus virginicus* var. *virginicus*), *Poa poiformis* and Blue Wandering Jew (*Commelina cyanea*).

Variation: Variant 9a: dominated by Common Reed; **Variant 9b**: dominated by Couch; **Variant 9c**: dominated by Leafy Flat Sedge. Variants 9a and 9b could also be classified as Freshwater Wetlands (Keith 2004).



New Gulch with Variant 9a (Common Reed reedland) the pale brown patch on the right and Variant 9c (Leafy Flat Sedge) the pale patch on the left.

Variant 9a: Common Reed reedland.

Variant 9b: Couch grassland.

Habitat: This community mainly occurs along valleys and drainage lines in the northern hills on North Ridge basalt. Sedgelands dominated by *Cyperus lucidus* are also found on Roach Island and Muttonbird Island.

Sample sites: (*N* = 1) LHIFF17.

Floristic Group: 12.

Mean number of native species per plot: 10.

Indicator native species: *Phragmites australis*, *Cyperus lucidus*, *Crinum pedunculatum*.

Number of exotic species recorded in plots: 1.

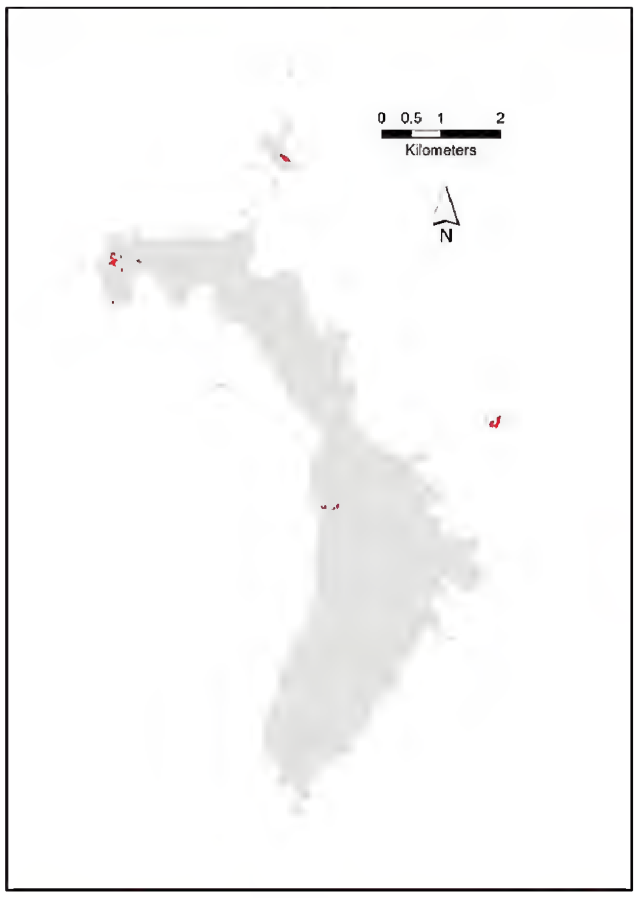
Common exotic species: *Aster subulatus, Ipomoea cairica*.

Disturbance and Condition: The condition of this community varies: the small site near North Bay (Variant 9b) is weedy, whereas other sites have few weeds (note that Couch [*Cynodon dactylon*] is treated by Green [1994] as a naturalised species in the LHIG, but the National Herbarium of NSW [PlantNET 2015] regards this species as native). The North Bay site was probably originally dominated by Leafy Flat Sedge and Crinum Lily. Areas on offshore islands, such as Roach and Muttonbird Islands, are constantly disturbed by nesting seabirds.

Areal extent: 2.25 ha (0.15% of mapped area).

Areal extent and % of type in PPP: 2.07 ha (92.12%).

Conservation significance and threats: Restricted to small areas. Occurrences on offshore islands provide nesting habitat for seabirds, and habitat for the Lord Howe Island Cockroach (*Panathesia lata*).



Key Diagnostic Species Floristic Group 12

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Phragmites australis	4	1	0	0	positive
Muehlenbeckia complexa	3	1	2	0.12	positive
Commelina cyanea	2	1	1	0.26	positive
**Ipomoea cairica*	2	1	1	0.24	positive
Lagunaria patersonia subsp. *patersonia*	2	1	1	0.29	positive
Poa poiformis var. *poiformis*	2	1	1	0.11	positive
Stephania japonica var. *timoriensis*	2	1	1	0.27	positive
Parsonsia howeana	4	1	2	0.61	constant

Heathlands — Coastal Headland Heaths

Community 10 Fishbone Fern – Boat Vine – Bat's Wing Fern fernland on boulder slopes at cliff bases

Scientific name: *Ficus macrophylla* subsp. *columnaris* – *Drypetes deplanchei* / *Nephrolepis cordifolia* – *Pandorea pandorana* subsp. *austrocaledonica* – *Microsorum pustulatum* subsp. *howense* – *Histiopteris incisa* / *Dendrobium gracilicaule* var. *howeanum* – *Peperomia urvilleana*.

Equivalent vegetation types: Mixed Fern and Herb (Pickard 1983); Mixed Fern and Herb (DECC 2007).

Structure: Closed to open low to tall fernland.

Description: There may be a sparse emergent layer of Banyan (*Ficus macrophylla* subsp. *columnaris*) with isolated Tea Tree (*Melaleuca howeana*) and Greybark (*Drypetes deplanchei*). Boat Vine (*Pandorea pandorana* subsp. *austrocaledonica*) is common in these shrubs as well as in the ground layer. The ground layer is rocky with an open cover dominated by Fishbone Fern (*Nephrolepis cordifolia*) and *Microsorum pustulatum* subsp. *howense*. The orchid *Dendrobium gracilicaule* var. *howeanum*, Elkhorn Fern (*Platycerium bifurcatum*) and *Peperomia urvilleana* are also common on the boulders.

Variation: The description of this community is based on sampling of a single low-altitude site. Other areas mapped as this community at higher altitudes are dominated by different fern and herb species, such as combinations of *Pteris microptera*, Bat's Wing Fern (*Histiopteris incisa*), *Carex brunnea* and *Elatostema reticulatum*. Emergent trees or shrubs at higher altitudes include Fitzgerald (*Dracophyllum fitzgeraldii*) and Big Mountain Palm (*Hedyscepe canterburyana*).

Habitat: Grows on steep talus slopes at the bases of cliffs and on boulder fields, mainly in the southern mountains.

Sample sites: (*N* = 1) LHIFF54.

Floristic Group: 14.

Mean number of native species per plot: 18.

Indicator native species: *Asplenium polyodon*, *Dendrobium gracilicaule* var. *howeanum*, *Nephrolepis cordifolia*, *Microsorum pustulatum* subsp. *howense*, *Pandorea pandorana* subsp. *austrocaledonica*, *Platycerium bifurcatum*; for higher altitude sites not sampled *Pteris microptera, Histiopteris incisa, Carex brunnea*, *Elatostema reticulatum*.

Number of exotic species recorded in plots: 4.

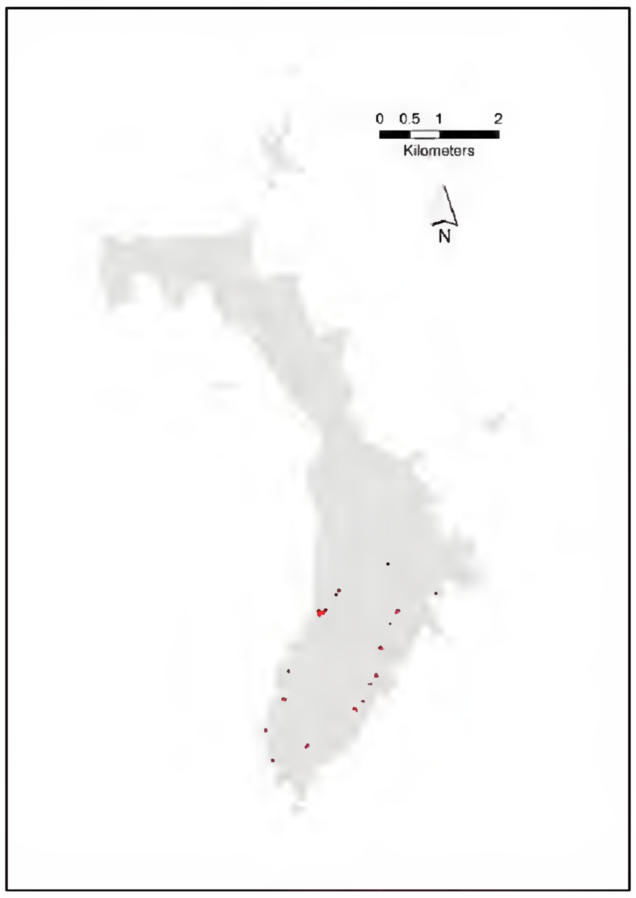
Common exotic species: *Ageratina adenophora*, *Lilium formosanum*.

Disturbance and Condition: Some sites have dense infestations of Crofton Weed (*Ageratina adenophora*) and Formosan Lily (*Lilium formosanum*) and are subject to natural disturbance from water and rock fall.

Areal extent: 1.78 ha (0.12% of island area).

Areal extent and % of type in PPP: 1.75 ha (98.38%).

Conservation significance and threats: A highly restricted community threatened by weed invasion.



Key Diagnostic Species Floristic Group 14

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Pandorea pandorana subsp. *austrocaledonica*	4	1	1	0.45	positive
Nephrolepis cordifolia	3	1	2	0.17	positive
Microsorum pustulatum subsp. *howense*	3	1	2	0.47	positive
Platycerium bifurcatum	3	1	1	0.26	positive
Asplenium polyodon	2	1	1	0.02	positive
Dendrobium gracilicaule var. *howeanum*	2	1	1	0.21	positive
**Lilium formosanum*	2	1	1	0.22	positive
Peperomia urvilleana	2	1	2	0.08	positive
**Digitaria ciliaris*	1	1	0	0	positive

Heathlands — Coastal Headland Heaths

Community 11 Bully Bush – Tea Tree – Mountain Daisy rocky heathland of the southern mountains

Scientific name: *Cassinia tenuifolia – Dracophyllum fitzgeraldii – Melaleuca howeana – Olearia ballii / Dendrobium moorei – Ficinia nodosa – Hydrocotyle hirta.*

Equivalent vegetation types: Probably related to Cliffs (Pickard 1983); related to *Alyxia squamulosa – Coprosma inopinata* Dwarf Scrub (DECC 2007).

Structure: Mid-high open shrubland.

Description: An open shrubland dominated by Bully Bush (*Cassinia tenuifolia*), Tea Tree (*Melaleuca howeana*) and Mountain Daisy (*Olearia ballii*), with *Xylosma parvifolia*, *Westringia viminalis* and *Pimelea congesta* also present. The sparse ground cover consists of *Poa poiformis* var. *poiformis*, Club Rush (*Ficinia nodosa*), *Euchiton involucratus*, Pennywort (*Hydrocotyle hirta*) and *Brachyscome segmentosa.* Ferns such as Coarse Maidenhair Fern (*Adiantum hispidulum*) and Horseshoe Fern (*Pyrrosia confluens*) also occur. Two species of ground orchid were recorded in the community: *Pterostylis curta* and an undescribed species of *Corybas*.

Variation: Similar shrubland communities, such as Community 25, occur on difficult-to-access rocky ridges.

Habitat: Found on exposed ridges at intermediate to high altitude in the southern mountains. Soils are very shallow and rocky with frequent rock outcrops.

Sample sites: (*N* = 1) LHIFF76.

Floristic Group: 15.

Mean number of native species per plot: 29.

Indicator native species: *Cassinia tenuifolia*, *Dendrobium moorei*, *Dracophyllum fitzgeraldii*, *Ficinia nodosa*, *Hydrocotyle hirta*, *Melaleuca howeana*, *Olearia ballii*, *Xylosma parvifolia.*

Number of exotic species recorded in plots: 6.

Common exotic species: *Hypochaeris radicata, Lilium formosanum.*

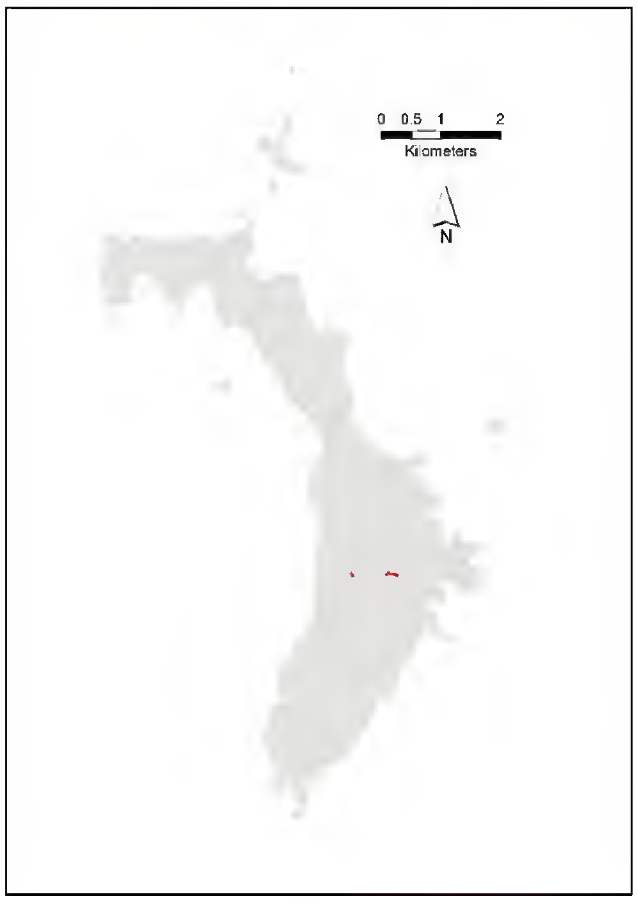
Threatened species: *Xylosma parvifolia* (Endangered – *BC Act*).

Disturbance and Condition: Apart from occurrence of weeds at low density, this community is generally in good condition.

Areal extent: 0.3 ha (0.02% of mapped area).

Areal extent and % of type in PPP: 0.3 ha (100%).

Conservation significance and threats: A highly restricted community with a number of rare and endemic species.



Key Diagnostic Species Floristic Group 15

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Cassinia tenuifolia	3	1	1	0.25	positive
Adiantum hispidulum	2	1	1	0.17	positive
Dendrobium moorei	2	1	1	0.11	positive
Dracophyllum fitzgeraldii	2	1	1	0.11	positive
Euchiton involucratus	2	1	1	0.01	positive
Ficinia nodosa	2	1	2	0.2	positive
Hydrocotyle hirta	2	1	1	0.02	positive
**Hypochaeris radicata*	2	1	2	0.06	positive
**Lilium formosanum*	2	1	1	0.22	positive
Melaleuca howeana	2	1	2	0.11	positive

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Melicope polybotrya	2	1	1	0.11	positive
Olearia ballii	2	1	1	0.01	positive
Pimelea congesta	2	1	2	0.05	positive
Poa poiformis var. *poiformis*	2	1	1	0.11	positive
Pterostylis curta	2	1	0	0	positive
Pyrrosia confluens var. *confluens*	2	1	0	0	positive
Westringia viminalis	2	1	1	0.01	positive
Brachyscome segmentosa	1	1	0	0	positive
Corybas spp.	1	1	0	0	positive
Echinopogon caespitosus var. *caespitosus*	1	1	0	0	positive
Lobelia anceps	1	1	0	0	positive
Luzula longiflora	1	1	0	0	positive
Wahlenbergia insulae-howei	1	1	0	0	positive
Xylosma parvifolia	1	1	0	0	positive

Rainforests — Oceanic Rainforests

Community 12 Kentia Palm – Banyan forest on sand or calcarenite of coastal lowlands

Scientific name: *Ficus macrophylla* subsp. *columnaris* / *Howea forsteriana* / *Asplenium milnei*.

Equivalent vegetation types: *Howea forsteriana* Megaphyllous Broad Sclerophyll Forest (Pickard 1983); Kentia Palm *Howea forsteriana* Closed Sclerophyll Forest (DECC 2007).

Variant 12a: Kentia Palm forest.

Structure: Mid-high to tall closed forest.

Description: A floristically simple tall forest dominated by Kentia Palm (*Howea forsteriana*) and Banyan (*Ficus macrophylla* subsp. *columnaris*). The ground is densely covered by fallen palm fronds and other tree species are sometimes present as scattered trees and seedlings. The upper, mid- and lower layers are represented by different aged cohorts of Kentia Palm. In both variants, trees and seedlings of other rainforest trees, such as Cotton-wood (*Celtis conferta* subsp. *amblyphylla*), Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*) and Sallywood (*Lagunaria patersonia* subsp. *patersonia*), are uncommon to rare. In some sites there is a sparse ground cover of combinations of *Asplenium milnei*, *Carex brunnea* and *Oplismenus imbecillis*.

Variation:

Variant 12a: Kentia Palm forest on coral sand and calcarenite. Stands are dominated by Kentia Palm with rare emergent Banyan; the mid- and lower layers are also dominated by Kentia Palm.

Variant 12b: Banyan – Kentia Palm forest on coral sand and calcarenite. Areas dominated by large emergent Banyan and Kentia Palm.

Habitat: Mainly found on deep sandy soils, mainly on Neds Beach Calcarenite, in sheltered areas on flat to undulating terrain. Occurrences on the eastern side of Mt Gower occur on talus slopes below basalt cliff lines.

Sample sites: (*N* = 3) LHIFF40, LHIFF41, LHIFF42.

Floristic Group: 16.

Mean number of native species per plot: 4.3 ± 3.0.

Indicator native species: *Ficus macrophylla* subsp. *columnaris*, *Howea forsteriana*.

Number of exotic species recorded in plots: 0.

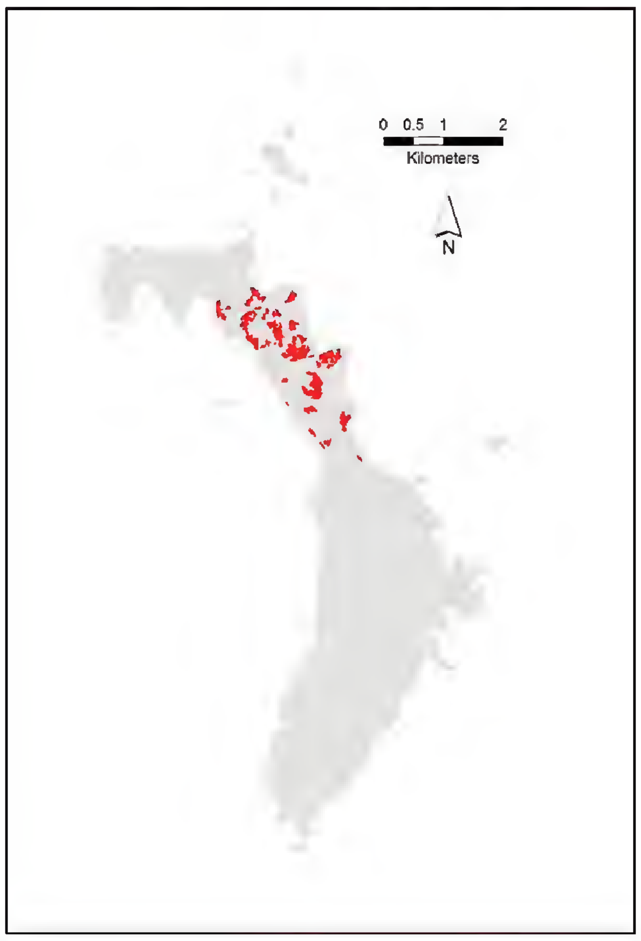
Common exotic species: *Asparagus plumosus*.

Disturbance and Condition: This community is generally in good condition. The ground surface is regularly disturbed by nesting Flesh-footed Shearwaters (*Ardenna carneipes*) between Neds Beach and Blinky Beach. Some areas within the Settlement area have populations of garden-escape weeds. Rodents eat the seed of the Kentia Palm and may affect regeneration of Palms. Some areas would have been cleared for grazing or urban development. Dieback has affected trees in this community where clearing has exposed it to salt-laden winds.

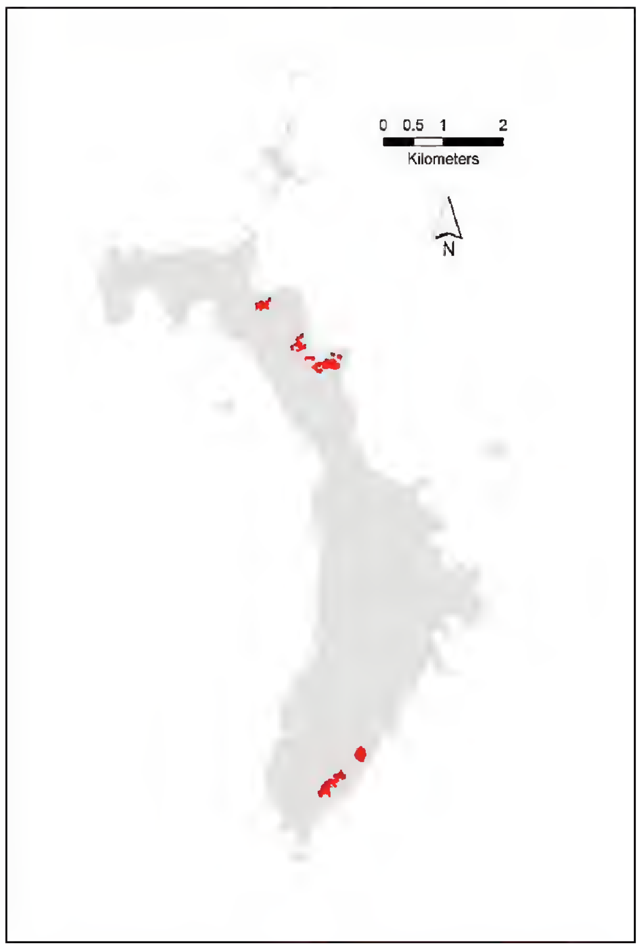
Areal extent: Variant 12a: 39.32 ha (2.62% of mapped area); Variant 12b: 18.07 ha (1.2% of island area).

Variant 12b: Banyan – Kentia Palm forest.

Areal extent and % of type in PPP: Variant 12a: 13.32 ha (33.89%); Variant 12b: 12.64 ha (69.95%).



Variant 12a



Variant 12b

Conservation significance and threats: This community provides the main nesting areas for Flesh-footed Shearwaters. Weeds and urban expansion could threaten this community.

Key Diagnostic Species Floristic Group 16

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Ficus macrophylla subsp. *columnaris*	5	0.67	1	0.10	positive
Howea forsteriana	4	1	2	0.31	positive
Drypetes deplanchei	1	0.67	2	0.66	negative
Cryptocarya triplinervis var. *triplinervis*	1	0.33	2	0.54	negative
Celtis conferta subsp. *amblyphylla*	2	0.33	2	0.29	uninformative
Howea belmoreana	2	0.33	3	0.37	uninformative
Asplenium milnei	1	0.33	1	0.48	uninformative
Lagunaria patersonia subsp. *patersonia*	1	0.33	2	0.30	uninformative
Olea paniculata	1	0.33	2	0.45	uninformative

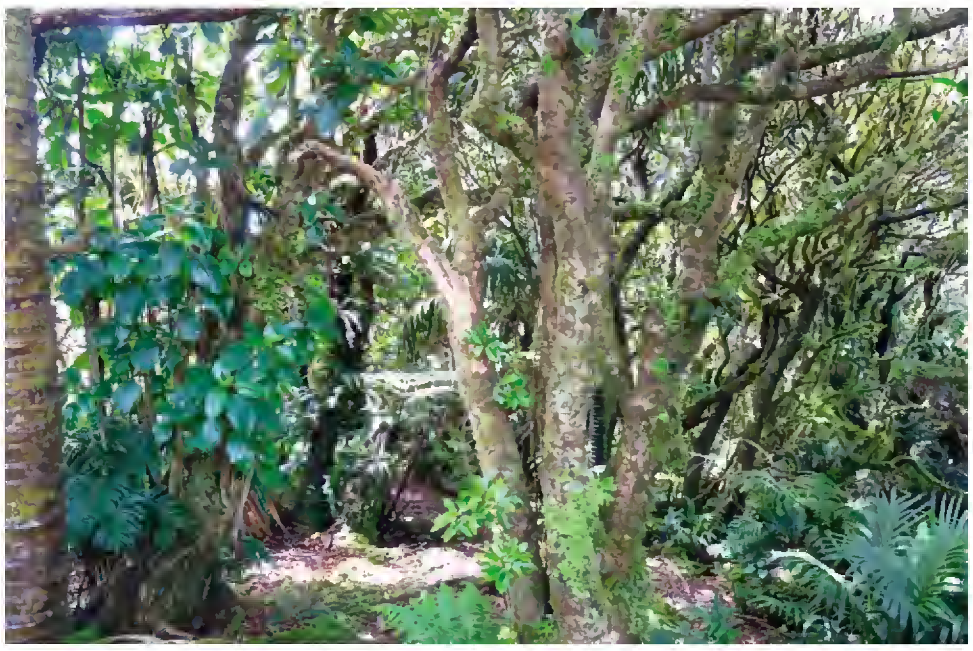
Rainforests — Oceanic Cloud Forests

Community 13 Hotbark – Fitzgerald – Big Mountain Palm – Mountain Rose oceanic closed forests of high-altitude parts of the southern mountains

Scientific name: *Bubbia howeana – Dracophyllum fitzgeraldii – Hedyscepe canterburyana – Metrosideros nervulosa / Negria rhabdothamnoides – Lepidorrhachis mooreana – Cyathea howeana / Elatostema reticulatum – Lastreopsis nephrodioides*.

Equivalent vegetation types: *Bubbia howeana – Dracophyllum fitzgeraldii* Gnarled Mossy All the best - Forest; *Hedyscepe canterburyana* Megaphyllous Broad Sclerophyll Forest; *Dracophyllum fitzgeraldii – Metrosideros nervulosa* Evergreen Broad Sclerophyll Scrub (Pickard 1983); *Bubbia howeana – Dracophyllum fitzgeraldii* Gnarled Mossy Forest; Big Mountain Palm *Hedyscepe canterburyana* Closed Sclerophyll Forest; *Dracophyllum fitzgeraldii – Metrosideros nervulosa* Closed Scrub (DECC 2007).

Structure: Dwarf to low closed forest.



Variant 13a: Hotbark – Fitzgerald gnarled mossy cloud forest.

Variant 13b: Mountain palm low closed forest.

Variant 13c: Fitzgerald – Mountain Rose low closed forest.

Description: A variable community in which Hotbark (*Bubbia howeana*), Fitzgerald (*Dracophyllum fitzgeraldii*) and Big Mountain Palm (*Hedyscepe canterburyana*) are always present and abundant in the upper to middle layers. Other species present in the upper stratum include Native Blackbutt (*Cryptocarya gregsonii*), Mountain Rose (*Metrosideros nervulosa*) and Island Apple (*Dysoxylum pachyphyllum*). Pumpkin Tree (*Negria rhabdothamnoides*) is abundant in the mid-layer. Epiphytic ferns and orchids, such as *Blechnum contiguum*, *Cephalomanes bauerianum* and *Dendrobium moorei*, as well as mosses, are common, particularly in the gnarled mossy cloud forest. The ground layer includes Rainforest Spinach (*Elatostema reticulatum*), *Lastreopsis nephrodioides* and *Carex brunnea*.

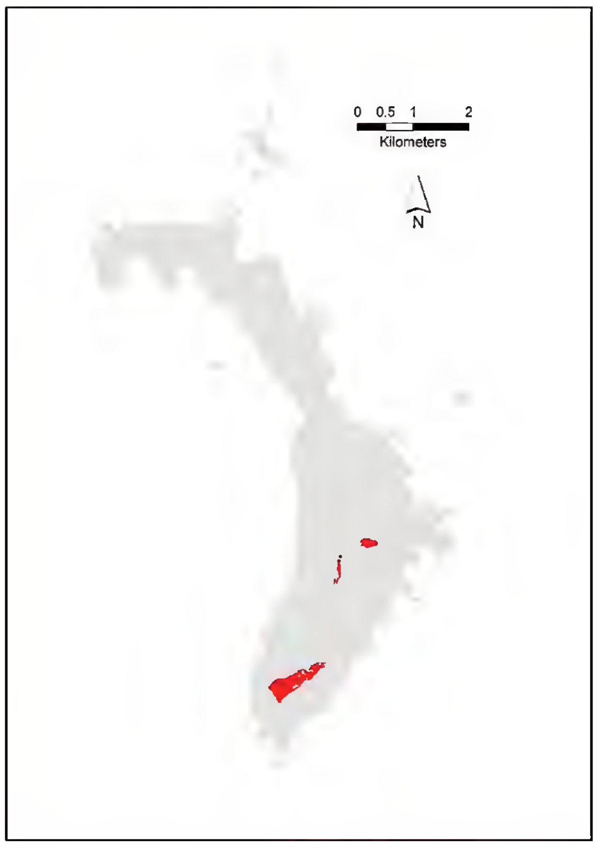
Variation:

Variant 13a: Hotbark – Fitzgerald gnarled mossy cloud forest. Areas in which Hotbark (*Bubbia howeana*), Fitzgerald (*Dracophyllum fitzgeraldii*) and Pumpkin Tree (*Negria rhabdothamnoides*) are most abundant and palms are less common.

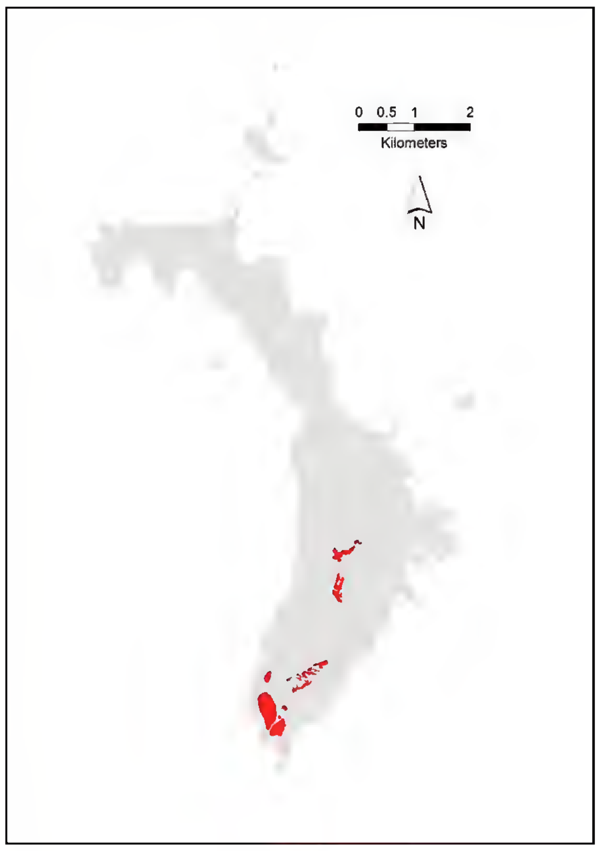
Variant 13b: Mountain palm low closed forest. Occurs in areas of the Mt Gower Plateau and the slopes of Mt Lidgbird where Little Mountain Palm (*Lepidorrhachis mooreana*) or Big Mountain Palm (*Hedyscepe canterburyana*), or both, are abundant.

Variant 13c: Fitzgerald – Mountain Rose low closed forest. Occurs on more exposed sites with shallow rocky soils and is dominated by Fitzgerald (*Dracophyllum fitzgeraldii*) and Mountain Rose (*Metrosideros nervulosa*).

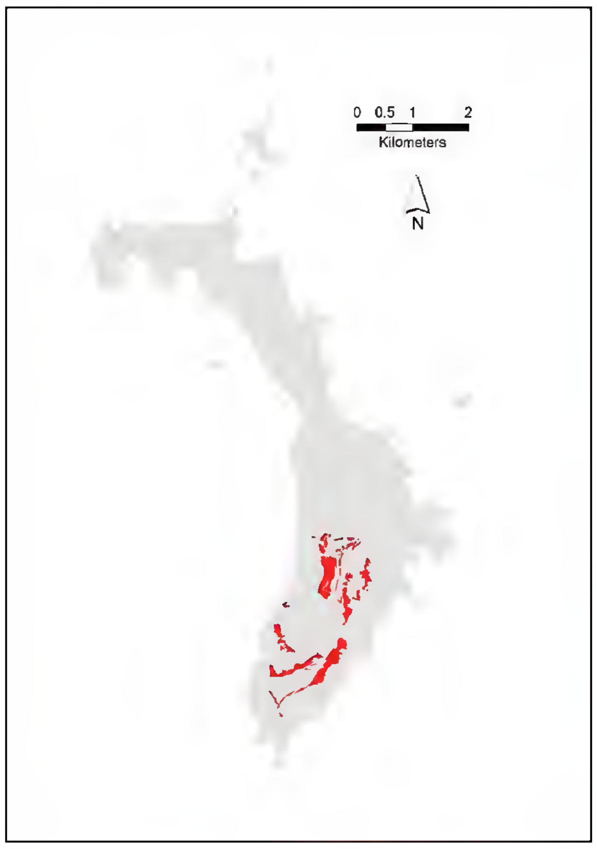
Habitat: Occurs at high altitudes on mountain slopes and plateaux of Mt Lidgbird and Mt Gower.



Variant 13a



Variant 13b



Variant 13c

Sample sites: (*N* = 5) LHIFF10, LHIFF30, LHIFF74, LHIFF75, LHIFF79.

Floristic Group: 17.

Mean number of native species per plot: 35.7 ± 10.3.

Indicator native species: *Negria rhabdothamnoides*, *Bubbia howeana*, *Hedyscepe canterburyana*, *Dracophyllum fitzgeraldii*, *Metrosideros nervulosa*, *Blechnum contiguum*, *Cyathea howeana*, *Elatostema reticulatum*.

Number of exotic species recorded in plots: 1.

Common exotic species: *Ageratina adenophora*.

Threatened species: *Carmichaelia exsul* (Endangered – *BC Act*); *Lepidorrhachis mooreana* (Critically Endangered – *BC Act*).

Disturbance and Condition: This community is generally in good condition, although disturbance from localised landslips and burrowing by Providence Petrels (*Pterodroma solandri*) can result in occurrence of weed species, particularly Crofton Weed (*Ageratina adenophora*).

Areal extent: Variant 13a: 25.92 ha (1.73% of island area); Variant 13b: 35.12 ha (2.34% of island area); Variant 13c: 68.78 ha (4.58% of island area).

Areal extent and % of type in PPP: Variant 13a: 25.92 ha (100%); Variant 13b: 35.12 ha (100%); Variant 13c: 68.78 ha (100%).

Conservation significance and threats: This community is restricted in distribution, is dominated by endemic plant species, and provides habitat for threatened plant species. Given its occurrence at high altitude and dependence on high moisture levels, it is vulnerable to the effects of climate change. It also provides nesting habitat for Providence Petrels. Predation on palm seeds and seedlings by rodents is a threat to the survival of the community (Auld and Leishman 2015).

Endangered Ecological Community: Community 13a is equivalent to Gnarled Mossy Cloud Forest on Lord Howe Island Critically Endangered Ecological Community (CEEC). Parts of communities 13b and 13c are also equivalent to this CEEC, particularly where they occur on the summit areas of the mountains.

Key Diagnostic Species Floristic Group 17

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Dracophyllum fitzgeraldii	3	1	1	0.06	positive
Bubbia howeana	3	1	1	0.15	positive
Elatostema reticulatum	3	0.8	2	0.06	positive
Lepidorrhachis mooreana	3	0.2	0	0	positive
Hedyscepe canterburyana	2	1	2	0.01	positive
Negria rhabdothamnoides	2	1	0	0	positive
Cryptocarya gregsonii	2	0.8	0	0	positive
Dendrobium moorei	2	0.8	1	0.07	positive
Dysoxylum pachyphyllum	2	0.8	1	0.26	positive
Lastreopsis nephrodioides	2	0.8	1	0.01	positive
Metrosideros nervulosa	2	0.8	2	0.05	positive
Pittosporum erioloma	2	0.6	1	0.03	positive
Polystichum whiteleggei	2	0.6	1	0.09	positive
Blechnum contiguum	2	0.4	0	0	positive
Blechnum patersonii subsp. *patersonii*	2	0.4	0	0	positive
Cephalomanes bauerianum	2	0.4	0	0	positive
Tmesipteris truncata	2	0.4	0	0	positive
Cyathea brevipinna	2	0.2	0	0	positive
Grammitis nudicarpa	2	0.2	0	0	positive
Hymenophyllum moorei	2	0.2	0	0	positive
Cyathea howeana	1	0.8	0	0	positive
Blechnum howeanum	1	0.6	0	0	positive
Elaeocarpus costatus	1	0.6	0	0	positive
Leptospermum polygalifolium subsp. *howense*	1	0.4	0	0	positive
Calanthe triplicata	1	0.2	0	0	positive
Grammitis wattsii	1	0.2	0	0	positive
Phlegmariurus varius	1	0.2	0	0	positive
Machaerina insularis	1	0.2	0	0	positive
Microsorum scandens	1	0.2	0	0	positive
Olearia mooneyi	1	0.2	0	0	positive
Pterostylis spp.	1	0.2	0	0	positive

Rainforests — Oceanic Rainforests

Community 14 Scalybark – Blue Plum – Curly Palm closed forest of sheltered slopes or valleys

Scientific name: *Syzygium fullagarii – Chionanthus quadristamineus / Howea belmoreana – Atractocarpus stipularis – Coprosma putida / Carex brunnea – Nephrolepis cordifolia – Pteris microptera*.

Equivalent vegetation types: *Cleistocalyx fullagarii* Rainforest (Pickard 1983); Scalybark (*Syzygium fullagarii*) Closed Forest (DECC 2007).

Structure: Tall to very tall closed forest.

Description: A forest community in which the canopy is clearly dominated by Scalybark (*Syzygium fullagarii*). Other less common trees include Blue Plum (*Chionanthus quadristamineus*), Cedar (*Guioa coriacea*), Forky-tree (*Pandanus forsteri*) and Island Apple (*Dysoxylum pachyphyllum*). There is a dense mid-layer of Curly Palm (*Howea belmoreana*), with Green Plum (*Atractocarpus stipularis*), Hotbark (*Bubbia howeana*), Stinkwood (*Coprosma putida*) and *Xylosma maidenii* also occurring. The epiphytic Elkhorn (*Platycerium bifurcatum*) is common on trees. There is a sparse ground layer of *Carex brunnea*, *Asplenium milnei*, *Pteris microptera* and *Microsorum pustulatum* subsp. *howense*. Fishbone Fern (*Nephrolepis cordifolia*) is occasionally common in rocky sites.

Habitat: Primarily occurs at low to mid-altitudes on sheltered slopes, with stony basalt soils, in the central hills and southern mountains. There are also small patches in the northern hills. Particularly common below Mt Gower in Erskine Valley, the eastern slopes below Mt Lidgbird, and on both sides of the Smoking Tree Ridge to Intermediate Hill.

Sample sites: (*N* = 6) LHIFF15, LHIFF18, LHIFF20, LHIFF45, LHIFF59, LHIFF83.

Floristic Group: 18.

Mean number of native species per plot: 18.7 ± 9.7.

Indicator native species: *Syzygium fullagarii*, *Howea belmoreana*, *Guioa coriacea*, *Chionanthus quadristamineus*, *Geniostoma huttonii*, *Platycerium bifurcatum*.

Number of exotic species recorded in plots: 0.

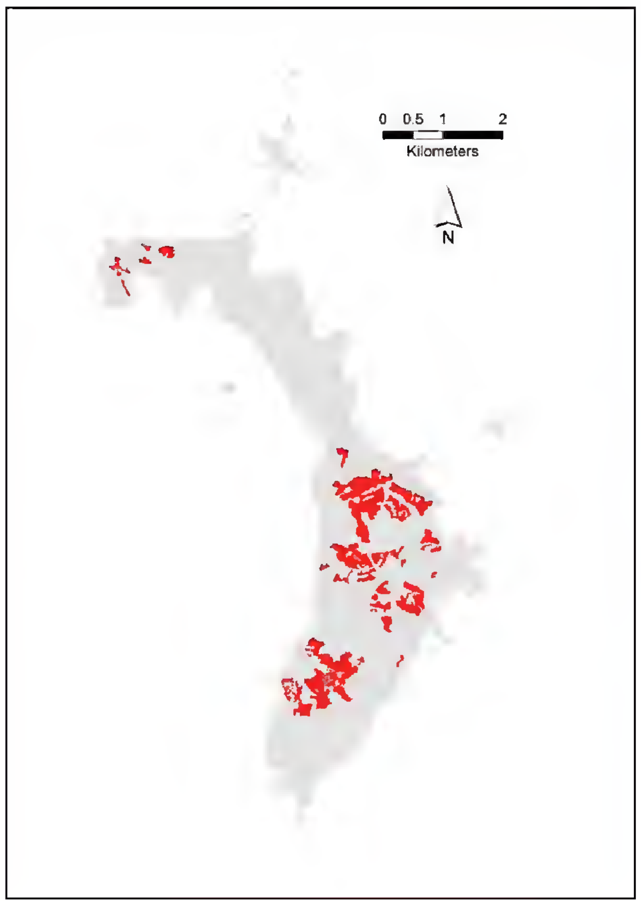
Common exotic species: *Asparagus aethiopicus*, *Psidium cattleyanum* var. *cattleyanum*, *Cenchrus clandestinus*.

Disturbance and Condition: Occurrences in the southern mountains (e.g. Erskine Valley) are in good condition with little disturbance, but some stands north of Mt Lidgbird and near-cleared areas are more at risk from weed invasion.

Areal extent: 196.12 ha (13.06% of mapped area).

Areal extent and % of type in PPP: 190.92 ha (97.35%).

Conservation significance and threats: A community dominated by endemic species and which provides nesting habitat for Providence Petrels (*Pterodroma solandri*). It is threatened by weed infestation where it is adjacent to cleared paddocks and Settlement areas, and dieback from exposure of the edge of the forest by clearing.



Key Diagnostic Species Floristic Group 18

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Howea belmoreana	3	1	3	0.33	positive
Syzygium fullagarii	3	1	2	0.3	positive
Chionanthus quadristamineus	3	0.67	2	0.15	positive
Guioa coriacea	2	1	2	0.34	positive
Atractocarpus stipularis	2	0.67	2	0.3	positive
Dysoxylum pachyphyllum	2	0.67	1	0.26	positive
Platycerium bifurcatum	2	0.67	1	0.24	positive
Carex brunnea	2	0.5	2	0.44	positive
Xylosma maidenii	2	0.5	2	0.34	positive
Geniostoma huttonii	1	0.17	0	0	positive
Drypetes deplanchei	2	0.67	2	0.66	constant
Nephrolepis cordifolia	3	0.33	2	0.16	uninformative
Sophora howinsula	3	0.33	1	0.12	uninformative

Rainforests — Oceanic Rainforests

Community 15 Blue Plum – Curly Palm – Scalybark – Forky-tree closed forest on rocky slopes and gullies

Scientific name: *Chionanthus quadristamineus* – *Howea belmoreana* – *Syzygium fullagarii* / *Geniostoma petiolosum* – *Coprosma* sp. nov. – *Coprosma putida* / *Nephrolepis cordifolia* – *Microsorum pustulatum* subsp. *howense* – *Carex brunnea*.

Equivalent vegetation types: *Chionanthus quadristamineus* Rainforest; *Howea belmoreana* Megaphyllous Broad Sclerophyll Forest; *Pandanus forsteri* Megaphyllous Broad Sclerophyll Forest (Pickard 1983); Blue Plum *Chionanthus quadristamineus* Closed Forest; Curly Palm *Howea belmoreana* Closed Sclerophyll Forest; *Pandanus forsteri* Closed Sclerophyll Forest (DECC 2007).

Variant 15a: Blue Plum – Curly Palm – Scalybark closed forest on rocky slopes.

Structure: Low to mid-high closed forest.

Description: A species-rich forest community in which Blue Plum (*Chionanthus quadristamineus*) is the dominant canopy species, with Curly Palm (*Howea belmoreana*) also abundant in either the canopy or the mid-storey. Other less common canopy species include Scalybark (*Syzygium fullagarii*), Cedar (*Guioa coriacea*), Island Apple (*Dysoxylum pachyphyllum*) and Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*). Common species in the mid-storey include *Coprosma* sp. nov., Stinkwood (*Coprosma putida*), Boar Tree (*Geniostoma petiolosum*) and Hill Rose (*Metrosideros sclerocarpa*). Fishbone Fern (*Nephrolepis cordifolia*), *Carex brunnea* and *Microsorum pustulatum* subsp. *howense* are the most common ground-cover species.

Variation:

Variant 15a: Blue Plum – Curly Palm – Scalybark closed forest on rocky slopes.

Variant 15b: Forky-tree closed forest along gullies. A variant occurring along creek lines and lower slopes that is dominated by Forky-tree (*Pandanus forsteri*). A community recognised by Pickard (1983) that was not discerned in the numerical analysis for this survey.

Variant 15b: Forky-tree closed forest along gullies.

Habitat: Occurs in the southern mountains, on Mt Lidgbird Basalt, at mid- to high altitudes.

Sample sites: (*N* = 7) LHIFF16, LHIFF19, LHIFF35, LHIFF47, LHIFF48, LHIFF53, LHIFF64.

Floristic Group: 20.

Mean number of native species per plot: 38.2 ± 3.3.

Indicator native species: *Chionanthus quadristamineus*, *Howea belmoreana*, *Geniostoma petiolosum*, *Coprosma* sp. nov., *Coprosma putida*, *Nephrolepis cordifolia*, *Microsorum pustulatum* subsp. *howense*.

Number of exotic species recorded in plots: 5.

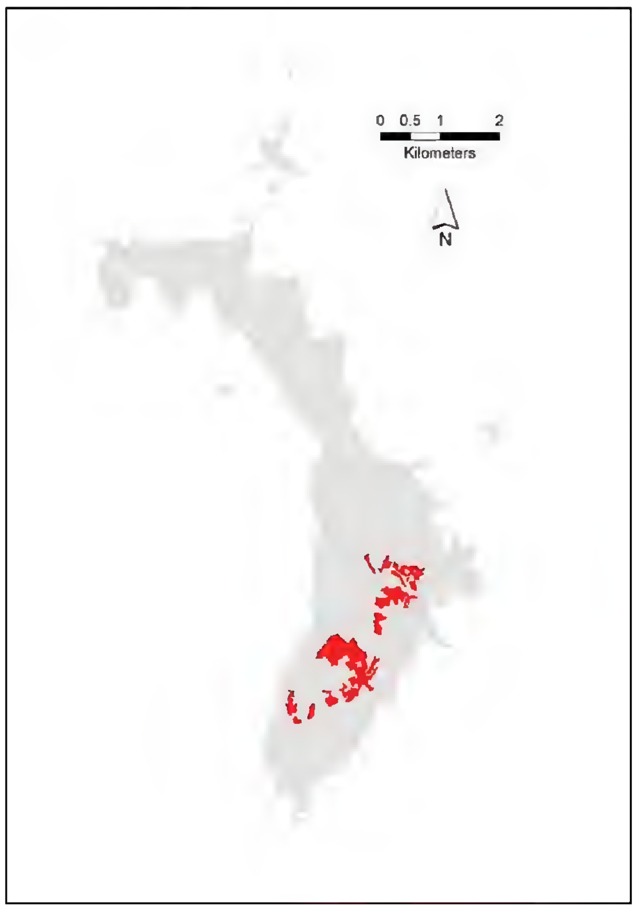
Common exotic species: *Ageratina adenophora*, *Lilium formosanum*.

Disturbance and Condition: This vegetation type is generally in good condition with minor weed infestations, and little disturbance apart from natural landslips.

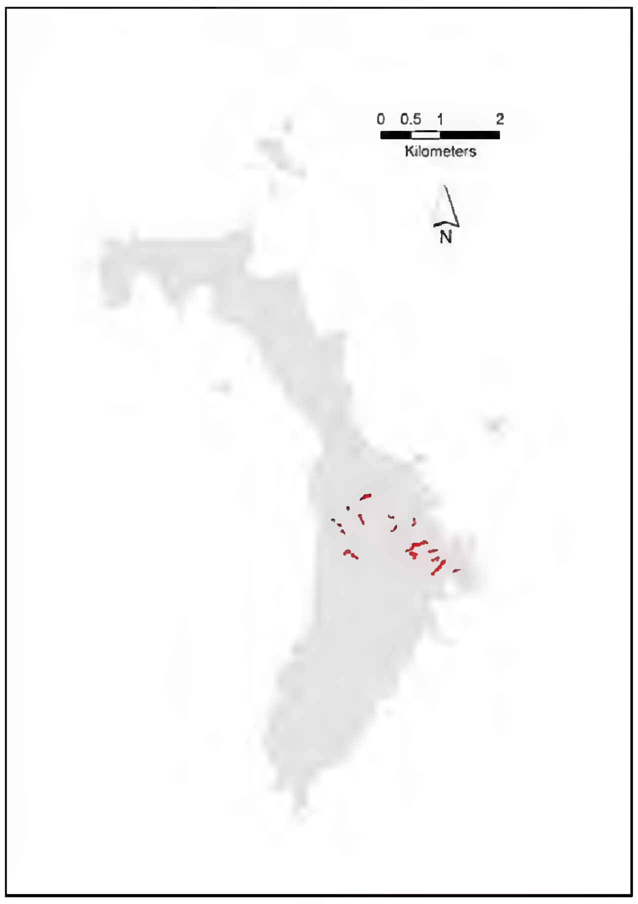
Areal extent: Variant 15a: 78.39 ha (5.22% of mapped area); Variant 15b: 6.37 ha (0.42% of mapped area).

Areal extent and % of type in PPP: Variant 15a: 78.39 ha (100%); Variant 15b: 6.32 ha (99.21%).

Conservation significance and threats: A community dominated by endemic species. It provides nesting habitat for Providence Petrels (*Pterodroma solandri*).



Variant 15a



Variant 15b

Key Diagnostic Species Floristic Group 20

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Howea belmoreana	4	0.86	3	0.33	positive
Chionanthus quadristamineus	4	0.71	2	0.14	positive
Syzygium fullagarii	3	0.71	3	0.32	positive
Nephrolepis cordifolia	2	1	2	0.10	positive
Microsorum pustulatum subsp. *howense*	2	1	2	0.43	positive
Carex brunnea	2	0.86	2	0.41	positive
Geniostoma petiolosum	2	0.86	1	0.14	positive
Guioa coriacea	2	0.86	2	0.34	positive
Coprosma sp. nov	2	0.71	1	0.05	positive
Coprosma putida	2	0.71	2	0.25	positive
Elatostema reticulatum	2	0.71	3	0.05	positive
Marsdenia rostrata	2	0.57	1	0.06	positive
Metrosideros sclerocarpa	2	0.57	1	0.08	positive
Olea paniculata	2	0.57	2	0.43	positive
Peperomia tetraphylla	1	0.14	0	0	positive
**Potentilla indica*	1	0.14	0	0	positive
Psychotria carronis	1	0.14	0	0	positive
Drypetes deplanchei	2	0.86	2	0.65	constant
Parsonsia howeana	2	0.71	2	0.61	constant
Howea forsteriana	3	0.14	3	0.35	uninformative

Rainforests — Oceanic Rainforests

Community 16 Scalybark – Curly Palm – Greybark – Cedar – Maulwood – Forky-tree lowland mixed closed forest on slopes of the Southern Mountains

Scientific name: *Syzygium fullagarii – Howea belmoreana – Drypetes deplanchei – Guioa coriacea / Pandanus forsteri – Xylosma maidenii – Atractocarpus stipularis – Coprosma putida – Smilax australis / Asplenium milnei – Oplismenus imbecillis.*

Equivalent vegetation types: Lowland Mixed Rainforest; *Howea belmoreana* Megaphyllous Broad Sclerophyll Forest (Pickard 1983); Lowland Mixed Closed Forest; Curly Palm *Howea belmoreana* Closed Sclerophyll Forest (DECC 2007).

Variant 16a: Scalybark – Curly Palm – Greybark – Cedar – Maulwood – Forky-tree lowland mixed closed forest on slopes of the Southern Mountains.

Structure: Mid-high to tall closed forest.

Description: This floristically diverse forest is characterised by a variable overstorey. The most common trees are Scalybark (*Syzygium fullagarii*), Curly Palm (*Howea belmoreana*), Greybark (*Drypetes deplanchei*), Cedar (*Guioa coriacea*), Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*), Maulwood (*Olea paniculata*) and Forky-tree (*Pandanus forsteri*). There is a mid-layer of Curly Palm (*Howea belmoreana*), Kentia Palm (*Howea forsteriana*), Green Plum (*Atractocarpus stipularis*), Stinkwood (*Coprosma putida*) and *Xylosma maidenii*. The ground layer comprises *Asplenium milnei*, *Carex brunnea* and *Oplismenus imbecillis*. Vines such as *Parsonsia howeana*, Lawyer Vine (*Smilax australis*), Whip Vine (*Flagellaria indica*) and jasmines (Stiff Jasmine *Jasminum volubile* and Jasmine *Jasminum didymum* var. *didymum*) are also common. The epiphytic fern Elkhorn (*Platycerium bifurcatum*) occurs frequently, usually growing on the trees.

Variant 16b: Curly Palm closed sclerophyll forest.

Variation:

Variant 16a: Scalybark – Curly Palm – Greybark – Cedar – Maulwood – Forky-tree lowland mixed closed forest on slopes of the southern mountains. This variant has a variable overstorey and is widespread in the central hills and around Mt Lidgbird in the southern mountains.

Variant 16b: Curly Palm closed sclerophyll forest. This variant is dominated by Curly Palm (*Howea belmoreana*) and occurs on slopes and gullies at mid- to low altitudes in the southern mountains and northern hills. It is uncommon in the central hills and lowlands.

Habitat: Occurs on basalt and breccia at low to intermediate altitudes on gentle to moderate slopes, usually on mid-slopes or gullies.

Sites: (*N* = 16) LHIFF13, LHIFF14, LHIFF26, LHIFF31, LHIFF32, LHIFF33, LHIFF44, LHIFF46, LHIFF50, LHIFF52, LHIFF56, LHIFF58, LHIFF63, LHIFF78, LHIFF81, LHIFF84.

Floristic Group: 21.

Mean number of native species per plot: 29 ± 5.8.

Indicator native species: *Howea belmoreana*, *Guioa coriacea*, *Drypetes deplanchei*, *Xylosma maidenii*, *Atractocarpus stipularis*, *Smilax australis*, *Asplenium milnei*, *Oplismenus imbecillis*.

Number of exotic species recorded in plots: 7.

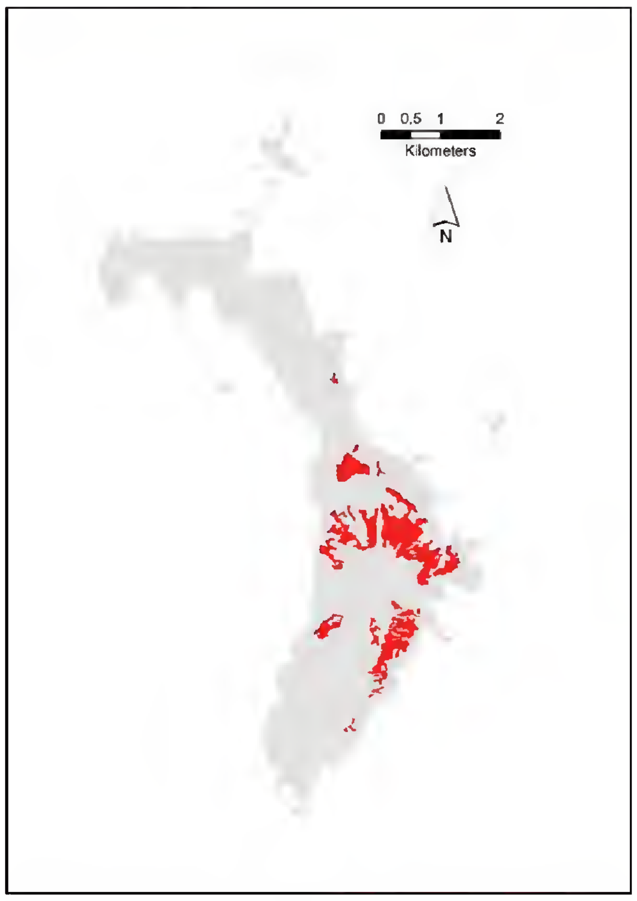
Common exotic species: *Lilium formosum*, *Asparagus aethiopicus*, *Psidium cattleyanum* var. *cattleyanum*.

Disturbance and Condition: Generally in good condition although some areas, particularly at low elevation near cleared land or the Settlement area, are affected by weeds.

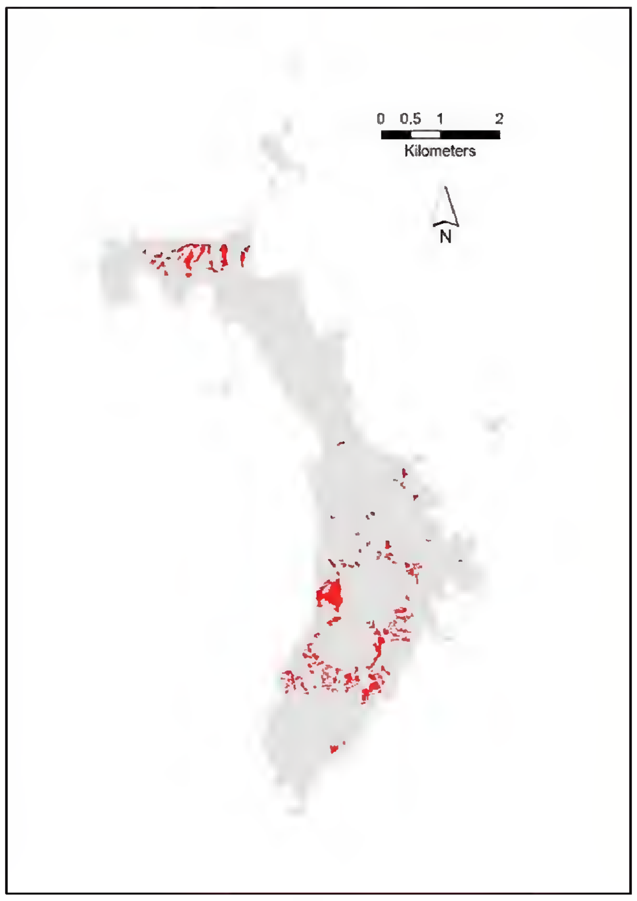
Areal extent: Variant 16a: 168.02 ha (11.19% of mapped area); Variant 16b: 77.46 ha (5.16% of mapped area).

Areal extent and % of type in PPP: Variant 16a: 166.34 ha (99%); Variant 16b: 76.48 ha (98.74%).

Conservation significance and threats: A community dominated by endemic species. Provides nesting habitat for Providence Petrels (*Pterodroma solandri*).



Variant 16a



Variant 16b

Key Diagnostic Species Floristic Group 21

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Howea belmoreana	3	0.88	3	0.26	positive
Syzygium fullagarii	3	0.69	3	0.27	positive
Smilax australis	2	1	1	0.44	positive
Asplenium milnei	2	0.94	1	0.37	positive
Guioa coriacea	2	0.94	1	0.26	positive
Oplismenus imbecillis	2	0.94	2	0.34	positive
Olea paniculata	2	0.88	2	0.34	positive
Pandanus forsteri	2	0.88	1	0.21	positive
Xylosma maidenii	2	0.88	1	0.23	positive
Carex brunnea	2	0.81	2	0.36	positive
Cryptocarya triplinervis var. *triplinervis*	2	0.81	2	0.47	positive
Atractocarpus stipularis	2	0.75	1	0.23	positive
Microsorum pustulatum subsp. *howense*	2	0.75	2	0.41	positive
Coprosma putida	2	0.69	2	0.2	positive
Jasminum didymum subsp. *didymum*	2	0.63	2	0.19	positive
Jasminum volubile	2	0.63	1	0.23	positive
Geniostoma petiolosum	2	0.5	1	0.13	positive
Clematis glycinoides	1	0.13	0	0	positive
Alyxia squamulosa	1	0.06	0	0	positive
Mucuna gigantea subsp. *gigantea*	1	0.06	0	0	positive
Ophioglossum pendulum	1	0.06	0	0	positive
Pellaea paradoxa	1	0.06	0	0	positive
Pittosporum undulatum	1	0.06	0	0	positive
Drypetes deplanchei	3	0.88	2	0.61	constant
Parsonsia howeana	2	0.81	2	0.57	constant
Lagunaria patersonia subsp. *patersonia*	3	0.25	2	0.31	uninformative
Symplocos candelabrum	3	0.13	1	0.09	uninformative

Rainforests — Oceanic Rainforests

Community 17 Greybark – Blackbutt rainforest at low to intermediate altitudes

Scientific name: *Drypetes deplanchei – Cryptocarya triplinervis* var. *triplinervis – Olea paniculata – Celtis conferta* subsp. *amblyphylla / Myrsine platystigma – Alyxia ruscifolia / Smilax australis – Parsonsia howeana – Jasminum didymum* subsp. *didymum / Oplismenus imbecillis – Asplenium milnei – Carex brunnea.*

Equivalent vegetation types: *Drypetes australasica – Cryptocarya triplinervis* Rainforest; *Drypetes australasica – Cryptocarya triplinervis* Exposed Facies Rainforest; *Drypetes australasica – Cryptocarya triplinervis* Exposed Calcarenite Facies Rainforest (Pickard 1983); Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Closed Forest; Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Low Closed Forest on Exposed Basalt; Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Low Closed Forest on Exposed Calcarenite (DECC 2007).

Structure: Dwarf to tall closed forest.

Variant 17a: Greybark – Blackbutt rainforest.

Variant 17b: Greybark – Blackbutt low closed forest on exposed basalt slopes.

Variant 17c: Greybark – Blackbutt low closed forest on exposed calcarenite.

Description: This community varies structurally depending on the substrate and degree of exposure. Greybark (*Drypetes deplanchei*) and Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*) are usually dominant in the canopy. Other less common trees include Cotton-wood (*Celtis conferta* subsp. *amblyphylla*), Maulwood (*Olea paniculata*) and Sallywood (*Lagunaria patersonia* subsp. *patersonia*). There is a sparse to dense mid-layer of shrubs including Hopwood (*Dodonaea viscosa* subsp. *burmanniana*), *Myrsine platystigma*, Christmas Bush (*Alyxia ruscifolia*), *Xylosma maidenii* and Tamana (*Elaeodendron curtipendulum*). Vines such as Lawyer Vine (*Smilax australis*), jasmine (Stiff Jasmine [*Jasminum volubile*] and Jasmine [*J. didymum* subsp. *didymium*]) and *Parsonsia howeana* are common. Ground-layer species include *Carex brunnea*, *Asplenium milnei* and *Oplismenus imbecillis*.

Variation:

Variant 17a: Greybark – Blackbutt rainforest. This is a taller, more species-rich variant of the community, occurring on sheltered to intermediate aspects on deeper soils derived from basalt, breccia and calcarenite. Widespread on northern hills, central lowlands and hills and the southern mountains.

Variant 17b: Greybark – Blackbutt low closed forest on exposed basalt slopes. This variant occupies exposed sites on ridges and areas exposed to the ocean. It is often a low, viney, near-impenetrable scrub of Greybark and Hopwood. This variant is most common in the northern hills, less common in the central lowlands and southern mountains.

Variant 17c: Greybark – Blackbutt low closed forest on exposed calcarenite. A variant of the community recognised by Pickard (1983), occurring on a ridge of exposed calcarenite in the northern hills.

Habitat: This community is widespread at low to mid-altitudes, on exposed, sheltered and intermediate slopes, and in littoral locations exposed to the ocean.

Sample sites: (*N* = 12) LHIFF22, LHIFF23, LHIFF24, LHIFF25, LHIFF26, LHIFF27, LHIFF31, LHIFF38, LHIFF43, LHIFF49, LHIFF51, LHIFF69.

Floristic Group: 22.

Mean number of native species per plot: 26.5 ± 4.8.

Indicator native species: *Drypetes deplanchei*, *Cryptocarya triplinervis* var. *triplinervis*, *Olea paniculata*, *Myrsine platystigma*, *Alyxia ruscifolia*, *Smilax australis*, *Jasminum didymum* subsp. *didymum*, *Oplismenus imbecillis*.

Number of exotic species recorded in plots: 10.

Common exotic species: *Ageratina adenophora*, *Ipomoea cairica*, *Asparagus aethiopicus*, *Asparagus plumosus*, *Psidium cattleyanum* var. *cattleyanum*.

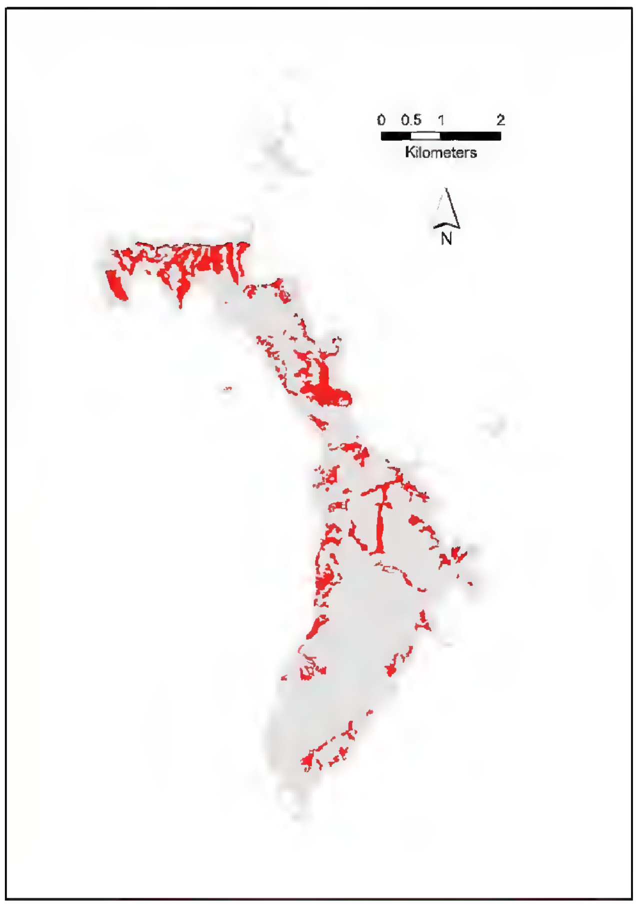
Threatened species: None recorded.

Disturbance and Condition: The condition of this community varies from good, with minor weed incursions, to poor with major weed infestations and edge effects from clearing near the Settlement and cleared areas. Significant areas, of Variant 17a in particular, would have been cleared for urban development and grazing.ss

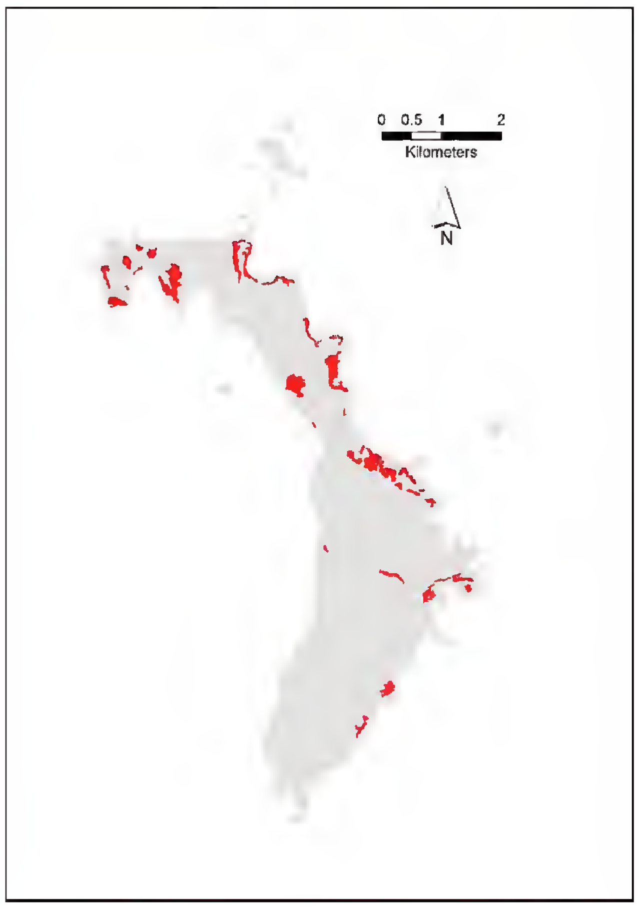
Areal extent: Variant 17a: 247.44 ha (16.48% of mapped area); Variant 17b: 80.52 ha (5.36% of mapped area); Variant 17c: 0.71 ha (0.05% of mapped area).

Areal extent and % of type in PPP: Variant 17a: 207.03 ha (83.67%); Variant 17b: 74.54 ha (92.57%); Variant 17c: 0.71 ha (100%).

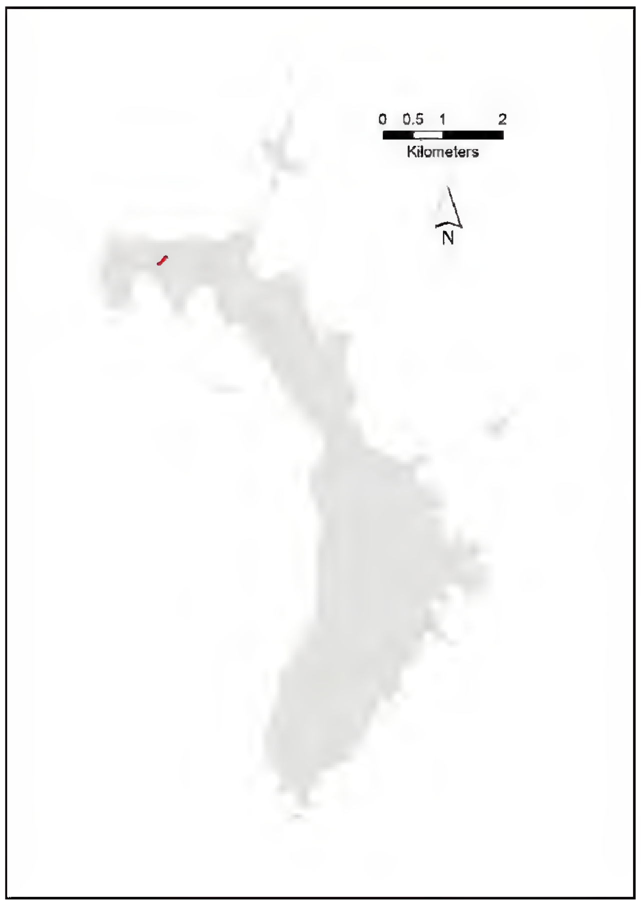
Conservation significance and threats: A widespread community that provides habitat for Lord Howe Woodhens (*Gallirallus sylvestris*), Lord Howe Flax Snail (*Placostylus bivaricosus*) and nesting Flesh-footed Shearwaters (*Ardenna carneipes*). It is threatened by weed invasion, exposure of edges and grazing, particularly in areas near the Settlement and cleared land.



Variant 17a



Variant 17b



Variant 17c

Key Diagnostic Species Floristic Group 22

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Cryptocarya triplinervis var. *triplinervis*	3	1	1	0.46	positive
Ochrosia elliptica	3	0.08	0	0	positive
Myrsine platystigma	2	1	1	0.22	positive
Olea paniculata	2	1	2	0.35	positive
Oplismenus imbecillis	2	1	2	0.36	positive
Smilax australis	2	1	1	0.47	positive
Jasminum didymum subsp. *didymum*	2	0.92	2	0.16	positive
Alyxia ruscifolia	2	0.83	1	0.37	positive
Jasminum volubile	2	0.83	1	0.22	positive
Asplenium milnei	2	0.67	1	0.45	positive
Dodonaea viscosa subsp. *burmanniana*	2	0.67	1	0.28	positive
Carex brunnea	2	0.58	2	0.42	positive
Celtis conferta subsp. *amblyphylla*	2	0.58	2	0.24	positive
Geitonoplesium cymosum	2	0.58	1	0.11	positive
Lagunaria patersonia subsp. *patersonia*	2	0.58	1	0.26	positive
Microsorum pustulatum subsp. *howense*	2	0.58	2	0.46	positive
Alyxia lindii	2	0.08	0	0	positive
Coprosma prisca	1	0.17	0	0	positive
Dianella intermedia	1	0.08	0	0	positive
Zanthoxylum pinnatum	1	0.08	0	0	positive
Drypetes deplanchei	3	1	2	0.61	constant
Parsonsia howeana	2	1	2	0.55	constant
**Ageratina adenophora*	4	0.17	1	0.10	uninformative
Cassinia tenuifolia	3	0.33	1	0.24	uninformative

Rainforests — Oceanic Rainforests

Community 18 Kentia Palm – Greybark rainforest of low to mid-altitude slopes

Scientific name: *Howea forsteriana – Drypetes deplanchei / Howea forsteriana – Homalanthus populifolius – Alyxia ruscifolia / Parsonsia howeana – Smilax australis / Oplismenus imbecillis – Psilotum nudum – Microsorum pustulatum* subsp. *howense*.

Equivalent vegetation types: Intermediate between *Drypetes australasica – Cryptocarya triplinervis* Rainforest and *Howea forsteriana* Megaphyllous Broad Sclerophyll Forest (Pickard 1983); intermediate between Kentia Palm (*Howea forsteriana*) Closed Sclerophyll Forest and Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Closed Forest (DECC 2007).

Structure: Mid-high to tall closed forest.

Description: A forest in which Kentia Palm (*Howea forsteriana*) and Greybark (*Drypetes deplanchei*) are common. Other trees are present at lower cover abundance and frequency including Forky-tree (*Pandanus forsteri*), Curly Palm (*Howea belmoreana*), Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*), Cotton-wood (*Celtis conferta* subsp. *amblyphylla*) and Tamana (*Elaeodendron curtipendulum*). There is a mid-layer of small rainforest trees and palms, including Kentia Palm, *Coprosma putida* and Dog Wood (*Homolanthus populifolius*). The ground layer is sparse and consists of *Microsorum pustulatum* subsp. *howense*, *Asplenium milnei*, Skeleton Fork-fern (*Psilotum nudum*) and *Oplismenus imbecillis*. The vines *Parsonsia howeana* and Lawyer Vine (*Smilax australis*) are also common in the ground and mid-layers.

Habitat: This community occurs on a range of habitats at low to mid-altitudes, often on sheltered lower to mid-slopes in the northern and central hills, and lower slopes in the southern mountains. It occurs on both basalt and calcarenite/coral derived soils.

Sample sites: (*N* = 4) LHIFF29, LHIFF34, LHIFF36, LHIFF39.

Floristic Group: 23.

Mean number of native species per plot: 18.5 ± 1.3.

Indicator native species: *Howea forsteriana*, *Drypetes deplanchei*, *Homalanthus populifolius*, *Alyxia ruscifolia*, *Parsonsia howeana*, *Oplismenus imbecillis*, *Psilotum nudum*, *Microsorum pustulatum* subsp. *howense*.

Number of exotic species recorded in plots: 6.

Common exotic species: *Lilium formosanum*, *Ipomoea cairica*.

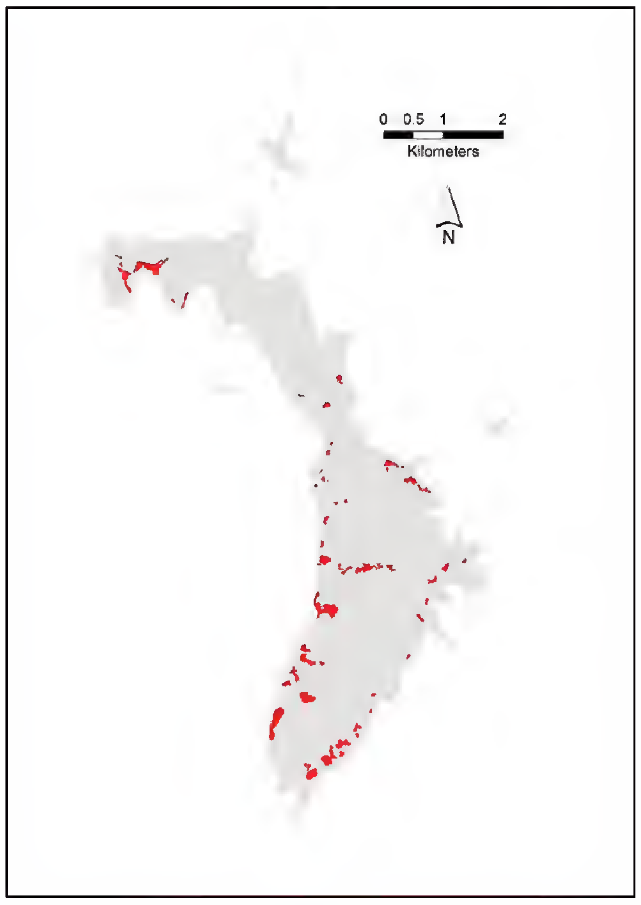
Threatened species: None recorded.

Disturbance and Condition: This community is generally in reasonable condition, although minor weed incursions occur, especially near habitation and cleared land.

Areal extent: 50.76 ha (3.38% of mapped area).

Areal extent and % of type in PPP: 47.22 ha (93.03%).

Conservation significance and threats: Provides habitat for Lord Howe Woodhens (*Gallirallus sylvestris*) and Lord Howe Flax Snail (*Placostylus bivaricosus*), and breeding habitat for Flesh-footed Shearwaters (*Ardenna carneipes*).



Key Diagnostic Species Floristic Group 23

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Howea forsteriana	4	1	2	0.31	positive
Homalanthus populifolius	2	1	1	0.28	positive
Oplismenus imbecillis	2	1	2	0.43	positive
Psilotum nudum	2	1	1	0.17	positive
Microsorum pustulatum subsp. *howense*	2	0.75	2	0.46	positive
Alyxia ruscifolia	2	0.5	1	0.43	positive
Carex brunnea	2	0.5	2	0.44	positive
Howea belmoreana	2	0.5	3	0.37	positive
**Lilium formosanum*	2	0.5	1	0.22	positive
Pandanus forsteri	2	0.5	1	0.33	positive
Drypetes deplanchei	3	1	2	0.65	constant
Parsonsia howeana	2	1	2	0.60	constant
Elaeodendron curtipendulum	3	0.25	1	0.15	uninformative

Rainforests — Oceanic Rainforests

Community 19 Maulwood – Kentia Palm – Cotton-wood – Greybark lowland forest

Scientific name: *Olea paniculata – Howea forsteriana – Celtis conferta* subsp. *amblyphylla – Drypetes deplanchei / Howea forsteriana – Parsonsia howeana – Flagellaria indica – Trophis scandens* subsp. *megacarpa / Asplenium milnei – Oplismenus imbecillis.*

Equivalent vegetation types: Intermediate between *Drypetes australasica – Cryptocarya triplinervis* Rainforest and *Howea forsteriana* Megaphyllous Broad Sclerophyll Forest (Pickard 1983); intermediate between Kentia Palm (*Howea forsteriana*) Closed Sclerophyll Forest and Greybark – Blackbutt (*Drypetes deplanchei – Cryptocarya triplinervis*) Closed Forest (DECC 2007).

Structure: Mid-high to very tall closed forest.

Description: A tall closed forest with a mixed canopy of Maulwood (*Olea paniculata*), Cotton-wood (*Celtis conferta* subsp. *amblyphylla*), Kentia Palm (*Howea forsteriana*), Banyan (*Ficus macrophylla* subsp. *columnaris*), Blackbutt (*Cryptocarya triplinervis* var. *triplinervis*), and Greybark (*Drypetes deplanchei*). There is a sparse mid-layer characterised by Kentia Palm and Cotton-wood. Vines are often present in various layers including *Parsonsia howeana*, *Trophis scandens* subsp. *megacarpa* and Lawyer Vine (*Smilax australis*). A sparse ground layer is sometimes present with *Asplenium milnei*, *Oplismenus imbecillis*, *Carex brunnea* and young palms.

Habitat: Occurs on flats to undulating hills in and around the Settlement area between the Clear Place and Old Settlement Beach, largely on Neds Beach Calcarenite but also on alluvial and marine sands and clays. Some of the best examples are located in Stevens Reserve.

Sample sites: (*N* = 5) LHIFF61, LHIFF65, LHIFF68, LHIFF72, LHIFF73.

Floristic Group: 24.

Mean number of native species per plot: 13.5 ± 5.1.

Indicator native species: *Cryptocarya triplinervis* var. *triplinervis*, *Drypetes deplanchei*, *Parsonsia howeana*, *Celtis conferta* subsp. *amblyphylla*, *Ficus macrophylla* subsp. *columnaris*, *Flagellaria indica*, *Howea forsteriana*, *Olea paniculata*, *Trophis scandens* subsp. *megacarpa*.

Number of exotic species recorded in plots: 1.

Common exotic species: *Ipomoea cairica*.

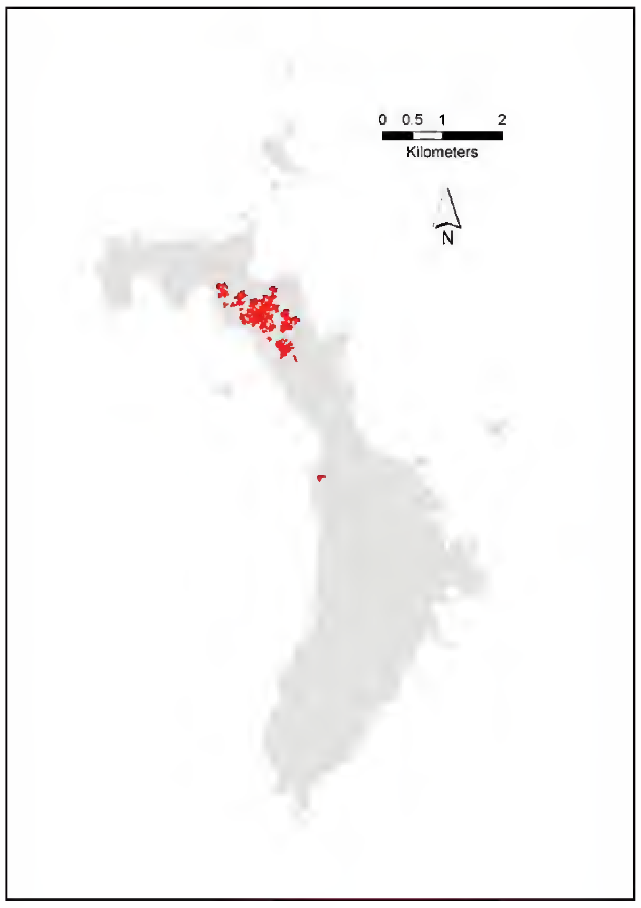
Threatened species: None recorded.

Disturbance and Condition: This community is in variable condition with some areas in good condition, but others affected by weeds (mainly garden escapes), and planted trees such as Camphor Laurel (*Cinnamomum camphora*) and Tallowwood (*Eucalyptus microcorys*) near Stevens Reserve.

Areal extent: 35.12 ha (2.34% of mapped area).

Areal extent and % of type in PPP: 0 ha (0%).

Conservation significance and threats: A community not recognised in previous studies that is restricted to the Settlement area and is not represented in the Permanent Park Preserve. It provides habitat for the Lord Howe Woodhen (*Gallirallus sylvestris*) and Lord Howe Flax Snail (*Placostylus bivaricosus*). A significant amount of this community has probably been cleared since human settlement and what remains is threatened by garden-escape weeds, clearing and die-back as a result of exposure from adjacent cleared areas.



Key Diagnostic Species Floristic Group 24

Scientific name	Group score	Group frequency	Non-group score	Non-group frequency	Fidelity class
Olea paniculata	4	1	2	0.41	positive
Howea forsteriana	3	1	2	0.30	positive
Celtis conferta subsp. *amblyphylla*	3	0.8	2	0.26	positive
Ficus macrophylla subsp. *columnaris*	3	0.6	1	0.09	positive
Trophis scandens subsp. *megacarpa*	2	0.8	1	0.35	positive
Flagellaria indica	2	0.6	1	0.33	positive
Cryptocarya triplinervis var. *triplinervis*	3	0.6	2	0.53	constant
Drypetes deplanchei	2	1	2	0.64	constant
Parsonsia howeana	2	1	2	0.59	constant
Guioa coriacea	3	0.2	2	0.40	uninformative
Pandorea pandorana subsp. *austrocaledonica*	3	0.4	1	0.46	uninformative
Howea belmoreana	3	0.2	3	0.38	uninformative

Saline Wetlands — Mangrove Swamps

Community 20 Grey Mangrove low open woodland of brackish creeks

Scientific name: *Avicennia marina* subsp. *australasica*.

Equivalent vegetation types: *Avicennia marina* var. *australasica* Open Broad Sclerophyll Scrub (Pickard 1983); Mangrove (*Avicennia marina* var. *australasica*) Open Swamp Scrub (DECC 2007).

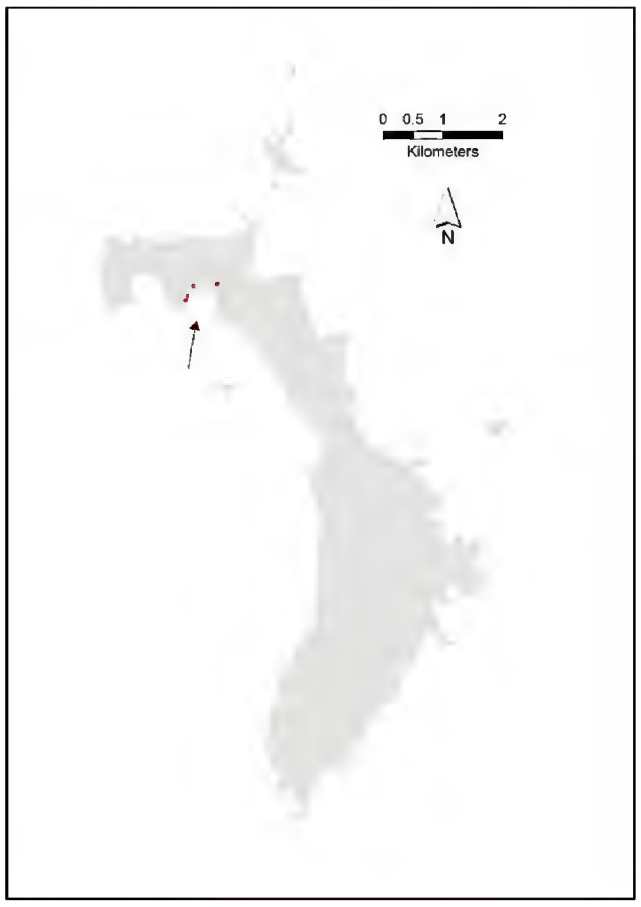
Description: Sampled in rapid floristic sites only and identified in the canopy-only floristic analysis. This community was not sampled with any full floristic plots during the current study owing to the extremely small extent of its distribution. Descriptions of this community are in Pickard (1983) and DECC (2007).

Sample sites: ($N = 1$) LHIRP06.

Areal extent: 0.015 ha (0.001% of mapped area).

Areal extent and % of type in PPP: 0 ha (0%).

Conservation significance and threats: An extremely restricted community represented by fewer than 50 individual adult Grey Mangrove plants located mainly at the mouth of Old Settlement Creek, with several scattered trees on the western shore of Hunter Bay. Potentially threatened by rising sea level.

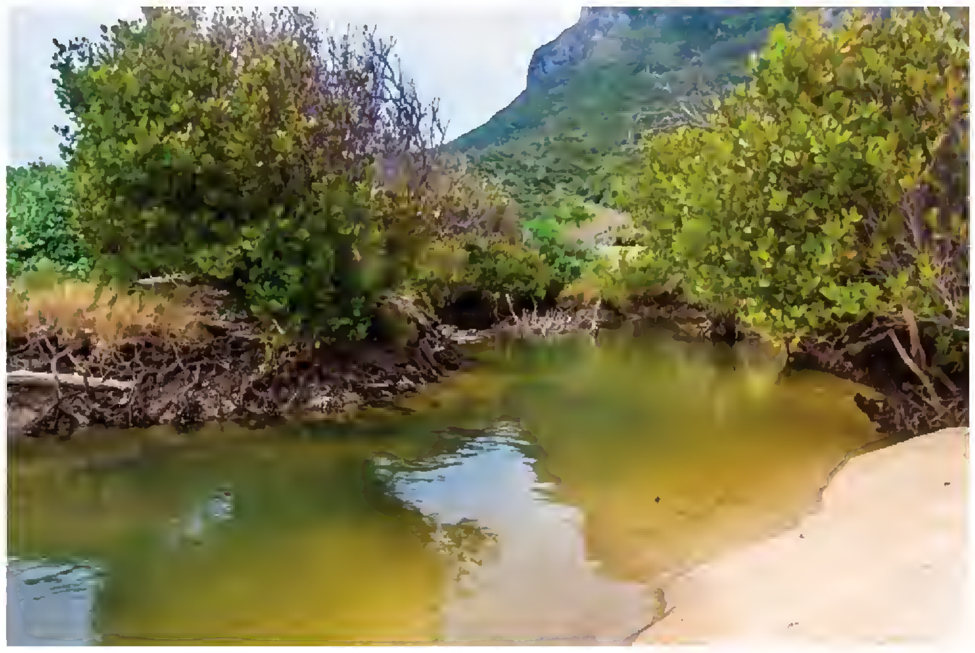


Saline Wetlands — Mangrove Swamps

Community 21 River Mangrove tall shrubland of brackish creeks

Scientific name: *Aegiceras corniculatum*.

Equivalent vegetation types: *Aegiceras corniculata* Broad Sclerophyll Swamp Scrub (Pickard 1983); Mangrove *Aegicerus corniculatum* Closed Swamp Scrub (DECC 2007).



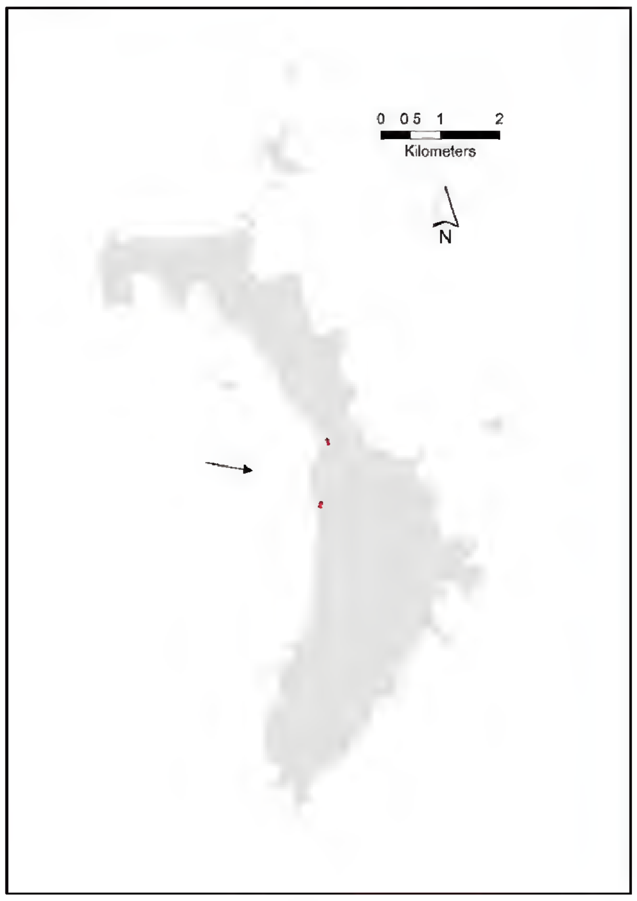
Description: Sampled in rapid floristic sites only and identified in the canopy-only floristic analysis. This community was not sampled with any full floristic plots during the current study owing to its extremely small distribution. Descriptions of this community can be found in Pickard (1983) and DECC (2007).

Sample sites: (*N* = 1) LHIRP07.

Areal extent: 0.14 ha (0.01% of island area).

Areal extent and % of type in PPP: 0 ha (0%).

Conservation significance and threats: An extremely restricted community occurring in very small patches at the mouths of Old Settlement Creek (too rare to map here), Soldiers Creek and Cobbys Corner. Threatened by invasion of pasture grasses, disturbance by cattle, and potentially threatened by rising sea level.

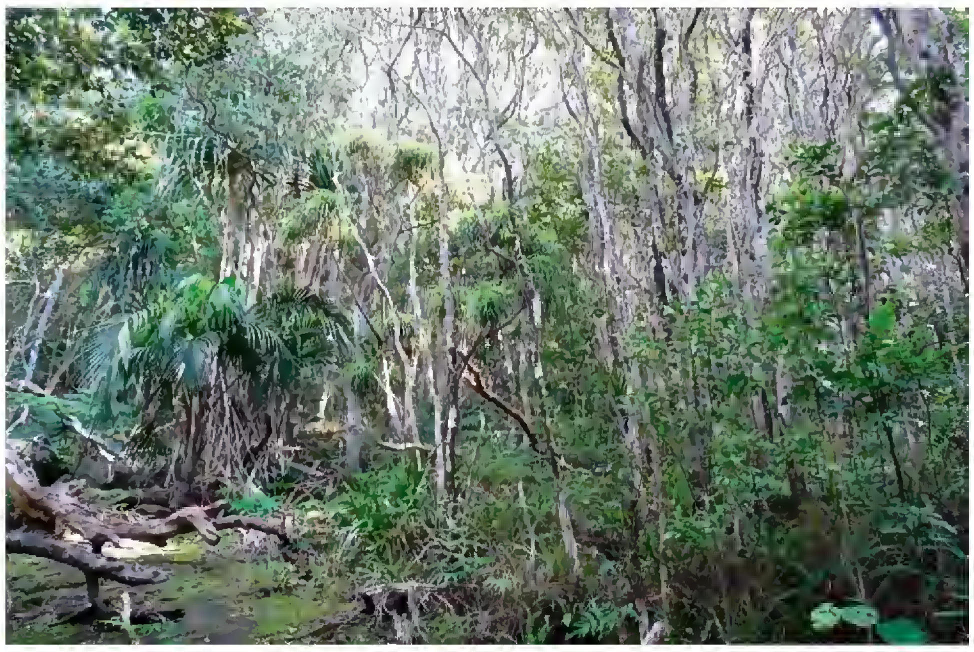


Rainforests — Oceanic Rainforests

Community 22 Hill Rose – Forky-tree forest of rocky creeks and slopes

Scientific name: *Metrosideros sclerocarpa – Pandanus forsteri – Chionanthus quadristamineus / Dracophyllum fitzgeraldii – Pandanus forsteri / Machaerina insularis – Carex brunnea – Microsorum pustulatum* subsp. *howense*.

Equivalent vegetation types: No clear equivalent vegetation types.



Structure: Low to mid-high open or closed forest.

Description: A community sampled in rapid floristic sites and identified in the canopy-only floristic analysis. Hill Rose (*Metrosideros sclerocarpa*) dominates, with Forky-tree (*Pandanus forsteri*) and Blue Plum (*Chionanthus quadristamineus*) often present. Other trees include Green Plum (*Atractocarpus stipularis*), Cedar (*Guioa coriacea*) and Scalybark (*Syzygium fullagarii*). Mid-layer species include Fitzgerald (*Dracophyllum fitzgeraldii*), Forky-tree and Hill Rose. Christmas Bush (*Alyxia ruscifolia*) is sometimes present. A sparse ground cover comprises *Carex brunnea*, *Microsorum pustulatum* subsp. *howense* and *Machaerina insularis*, which is the most common ground layer species at one site in Erskine Valley. The common name 'Hill Rose' is suggested here for *Metrosideros sclerocarpa* to avoid confusion with Mountain Rose used for *M. nervulosa* and which occurs at higher elevation than the former species.

Habitat: This community most commonly occurs on rocky riparian sites at low to mid-altitudes in the southern mountains. It is often associated with rocky creek beds such as Dinner Run, Rocky Run and Erskine Creek.

Sample sites: ($N = 3$) LHIRP117, LHIRP120, LHIRP129.

Indicator native species: *Metrosideros sclerocarpa*, *Pandanus forsteri*, *Machaerina insularis*.

Number of exotic species recorded in plots: 0.

Common exotic species: None recorded.

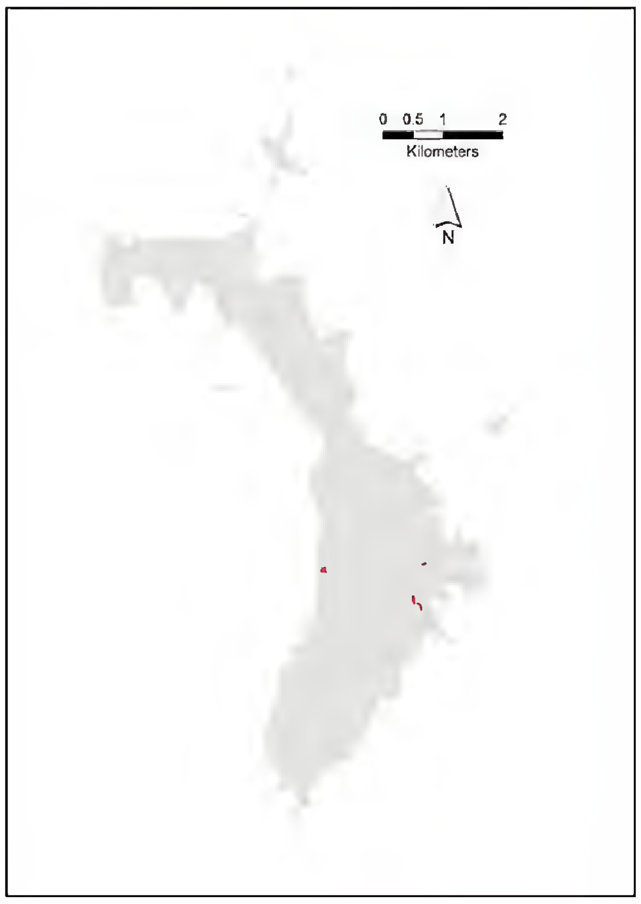
Threatened species: None recorded.

Disturbance and Condition: Generally in good condition and little disturbance other than from water flows in creeks.

Areal extent: 1.11 ha (0.07% of mapped area).

Areal extent and % of type in PPP: 1.11 ha (100%).

Conservation significance and threats: A community dominated by endemic species that occupies very small areas of a specific habitat. Not recognised in previous studies.



Grasslands — Maritime Grasslands

Community 23 *Poa poiformis* tussock grassland of offshore islands and exposed coastal slopes

Scientific name: *Poa poiformis – Commelina cyanea – Cyperus lucidus – Ficinia nodosa*.

Equivalent vegetation types: *Poa poiformis* Orthophyll Short Grass (Pickard 1983); *Poa poiformis* Grassland (DECC 2007).

Structure: Mid-high to tall tussock grassland.

Description: This community was not sampled with any full floristics plots during the current study owing to the difficulty in accessing the main occurrences on offshore islands. Descriptions of this community can be found in Pickard (1983) and DECC (2007). Excellent descriptions of the vegetation occurring on each offshore island that supports nesting seabirds are provided in Carlile and Priddel (2013a–f) and Carlile *et al.* (2013).

Habitat: Occurs on windswept offshore islands and headlands on the main island.

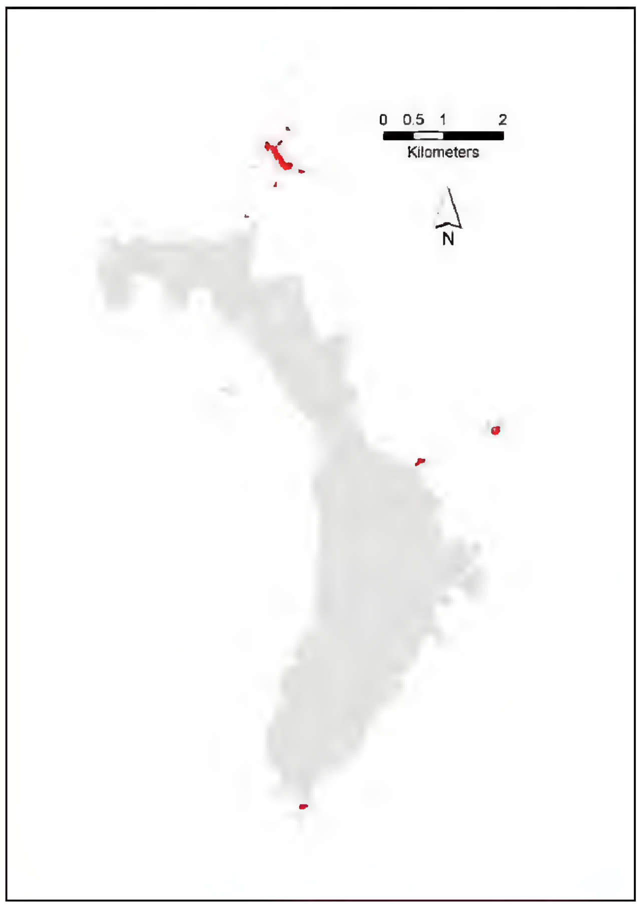
Indicator native species: *Poa poiformis*.

Disturbance and Condition: Offshore occurrences are generally in good condition apart from disturbance by nesting seabirds. The community on Blackburn Island is dominated by the exotic Rhodes Grass (*Chloris gayana*). Some occurrences on the main island are severely affected by Kikuyu (*Cenchrus clandestinus*).

Areal extent: 9.23 ha (0.61% of mapped area).

Areal extent and % of type in PPP: 9.23 ha (100%).

Conservation significance and threats: Provides key nesting sites for a number of seabird species, such as Masked Boobies (*Sula dactylatra*), Wedge-tailed Shearwaters (*Ardenna pacifica*) and Sooty Terns (*Onychoprion fuscata*).

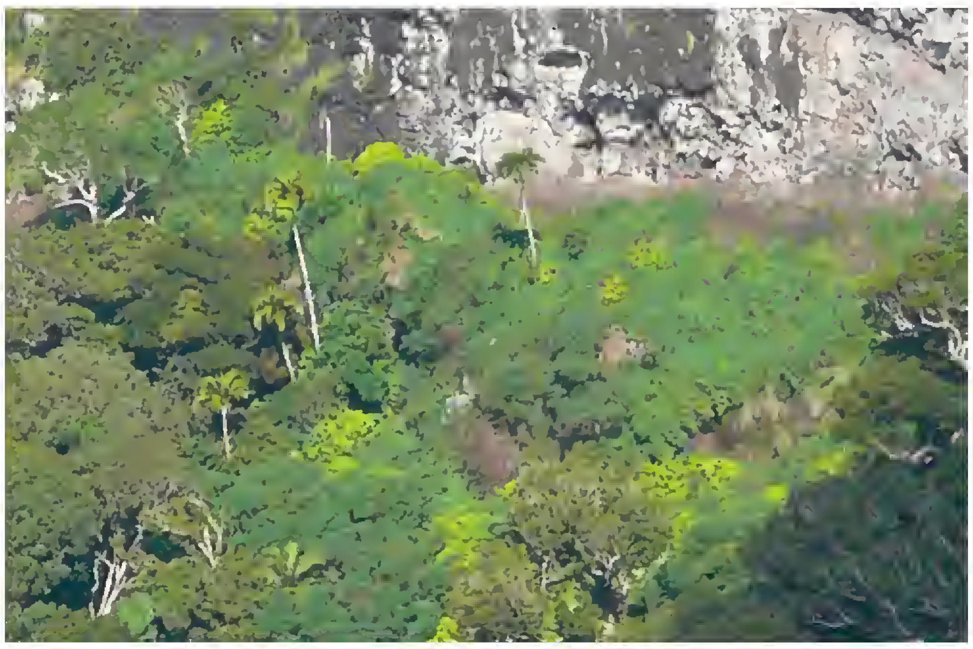


Rainforests — Oceanic Cloud Forests

Community 24 *Pouzolzia australis* – Kava closed shrubland on exposed wet rocky slopes

Scientific name: *Hedyscepe canterburyana – Negria rhabdothamnoides / Pouzolzia australis – Macropiper hooglandii / Elatostema reticulatum – Gahnia howeana – Machaerina insularis*.

Equivalent vegetation types: *Boehmeria calophleba – Macropiper excelsum* var. *psittacorum* Broad Orthophyll Scrub (Pickard 1983); *Boehmeria calophleba – Macropiper hooglandii* Closed Scrub (DECC 2007).



Structure: Tall to very tall closed shrubland.

Description: This community was not sampled during the current study owing to the difficulty accessing sites where it occurs. Descriptions of this community can be found in Pickard (1983) and DECC (2007).

Common exotic species: *Ageratina adenophora*.

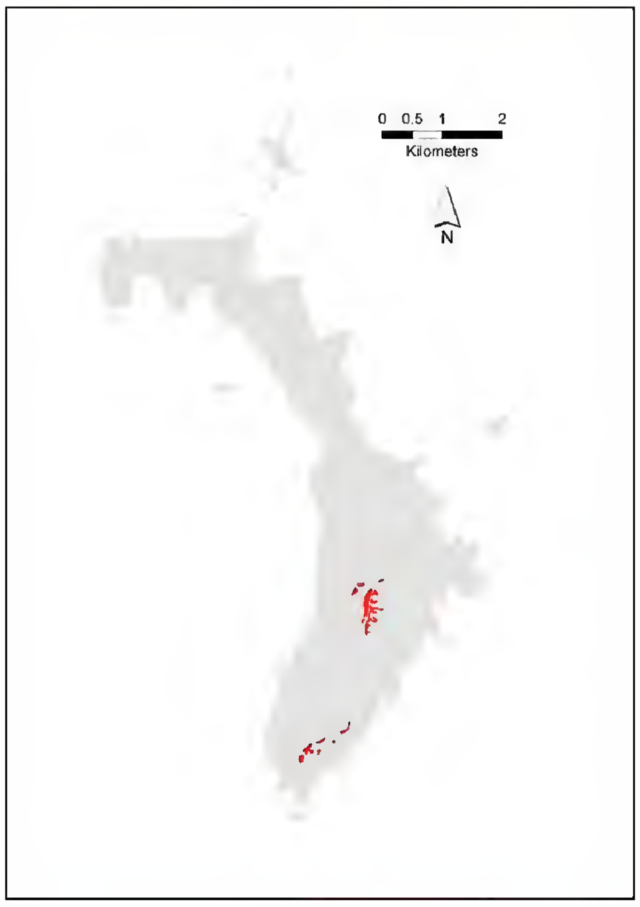
Threatened species: None recorded.

Disturbance and Condition: Areas at the foot of high cliffs on the south-eastern faces of Mounts Gower and Lidgbird (see image above) have been mapped as this community, but they are frequently disturbed by landslips and are drier than the higher elevation areas where this community also occurs. These cliff-base sites appear to be dominated by Kava (*Macropiper hooglandii*) and a variety of ferns, as well as often being heavily infested with Crofton Weed (*Ageratina adenophora*), and *Pouzolzia australis* may be absent.

Areal extent: 11.22 ha (0.75% of mapped area).

Areal extent and % of type in PPP: 11.22 ha (100%).

Conservation significance and threats: A restricted community supporting a suite of endemic plant species in a specific habitat. Despite its apparent remoteness, it is seriously threatened by Crofton Weed. Provides nesting habitat for Providence Petrels (*Pterodroma solandri*).



Heathlands — Coastal Headland Heaths

Community 25 *Alyxia squamulosa – Coprosma inopinata* low shrubland on narrow exposed rocky ridges

Scientific name: *Alyxia squamulosa – Coprosma inopinata – Xylosma parvifolia.*

Equivalent vegetation types: *Alyxia squamulosa – Coprosma inopinata* Dwarf Scrub (DECC 2007).

Structure: Dwarf to mid-high shrubland.

Description: This community was not sampled during the current study owing to the difficult access to sites where it occurs. Descriptions of this community can be found in Hutton (2001) and DECC (2007).

Habitat: Known from two exposed, high-elevation, narrow ridgelines – the ridgeline running south-east from 'The Pimple' on Mt Lidgbird (see above image) and the Razorback off Mt Gower.

Indicator native species: *Alyxia squamulosa*, *Coprosma inopinata*, *Xylosma parvifolia.*

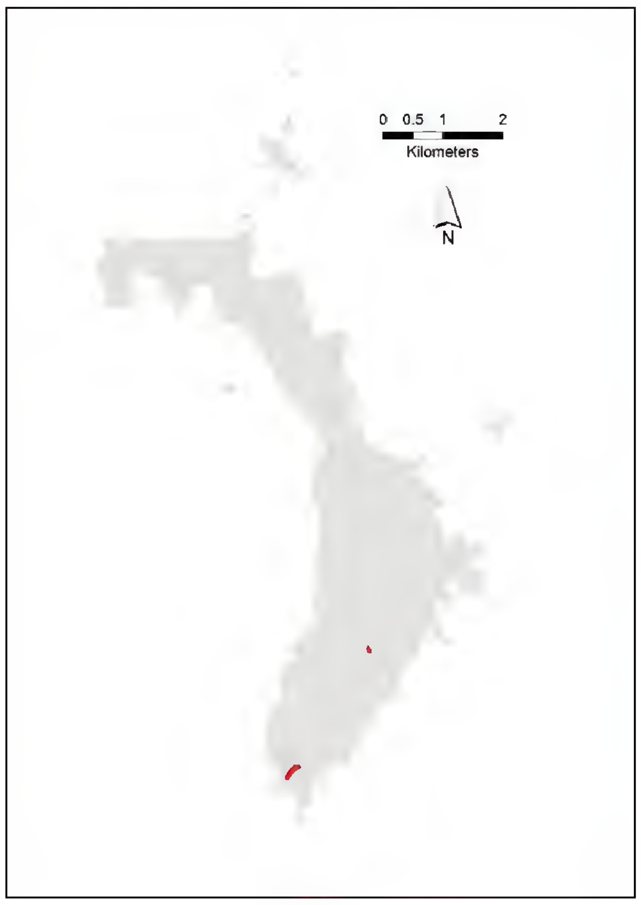
Threatened species: *Carmichaelia exsul*, *Coprosma inopinata*, *Geniostoma huttonii*, *Xylosma parvifolia* (all Endangered – *BC Act*).

Disturbance and Condition: Little disturbance, and generally no weeds recorded by Hutton (2001). However, recent surveys by S. Bower *et al.* (unpublished data) recorded *Solanum nigrum*, *Lilium formosanum*, *Ageratina adenophora* and other weeds at The Pimple site.

Areal extent: 0.89 ha (0.06% of mapped area).

Areal extent and % of type in PPP: 0.89 ha (100%).

Conservation significance and threats: An extremely restricted low shrubland community supporting a number of threatened endemic plant species. No threats apparent, apart from the potential for plants to be trampled by the very occasional, and foolhardy, bushwalker (Hutton 2001; DECC 2007).

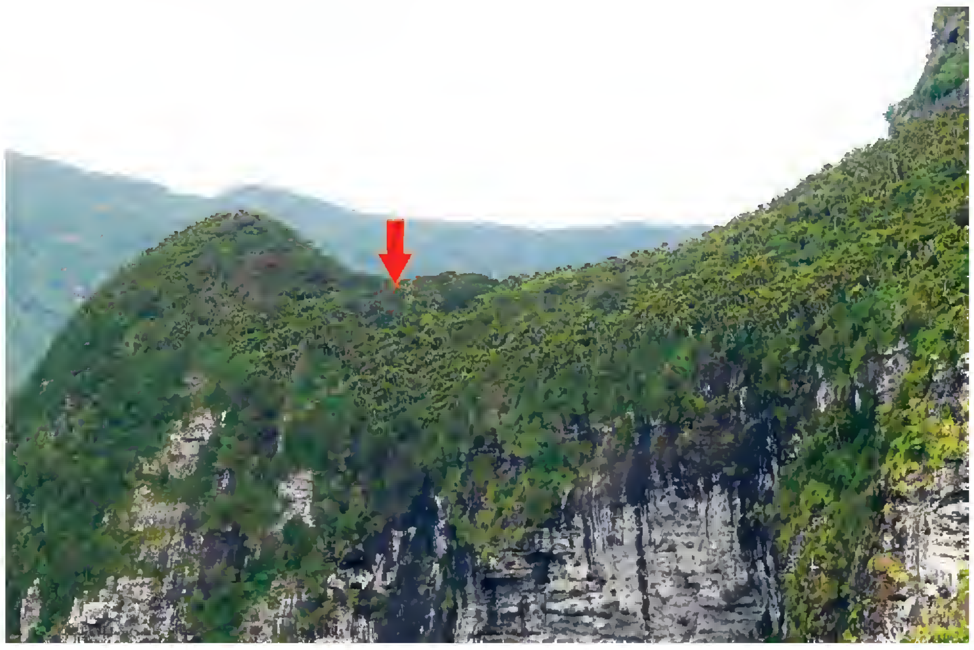


Rainforests — Oceanic Cloud Forests

Community 26 Black Plum – King Fern low closed forest of the southern mountains

Scientific name: *Cryptocarya gregsonii – Hedyscepe canterburyana / Marattia howeana / Asplenium pteridoides*.

Equivalent vegetation types: Part of *Cryptocarya gregsonii* Rainforest (Pickard 1983); part of *Cryptocarya gregsonii* Closed Forest (DECC 2007).



Structure: Low closed forest.

Description: This community was not sampled during the current study owing to the difficult access to sites where it occurs. Information for this community is from I. Hutton (pers. comm. 2013 – 2016). The canopy is dominated by Black Plum (*Cryptocarya gregsonii*) with occasional Big Mountain Palm (*Hedyscepe canterburyana*) and Fitzgerald (*Dracophyllum fitzgeraldii*). There is a mid-layer of King Fern (*Marattia howeana*) and *Macropiper hooglandii*, with a sparse ground layer of *Asplenium pteridoides* and *Pteris microptera*.

Habitat: Restricted to a small saddle on the southern spur of Mt Lidgbird (arrowed in above image). May also occur on the upper part of Little Pocket.

Indicator native species: *Cryptocarya gregsonii*, *Marattia howeana*.

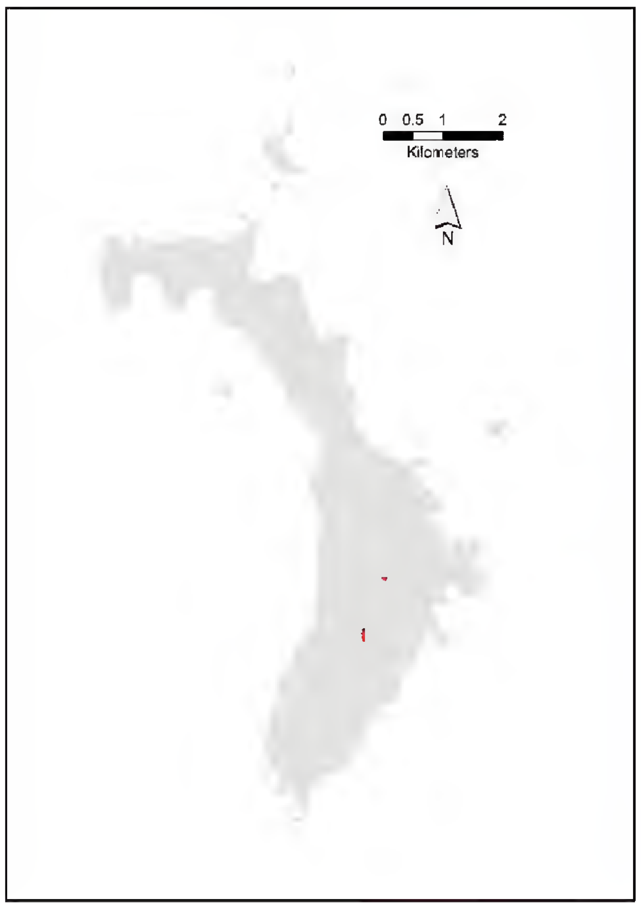
Common exotic species: None recorded.

Disturbance and Condition: In good condition although there is significant soil disturbance from nesting Providence Petrels (*Pterodroma solandri*).

Areal extent: 0.83 ha (0.06% of mapped area).

Areal extent and % of type in PPP: 0.83 ha (100%).

Conservation significance and threats: A very restricted community with several rare endemic species. Provides nesting habitat for Providence Petrels.



Appendix 2 List of plant species recorded in floristic sites

Taxa are listed alphabetically by family and genus within classes. Nomenclature follows that currently adopted by the National Herbarium of NSW, Royal Botanic Gardens, Sydney (PlantNet 2019). Status: * = Exotic taxon; BC-E = listed as Endangered under the NSW BC Act.

Class / Family	Status	Scientific name	Authority	Common name
Class Lycopsida - Club Mosses and Quill Worts				
Lycopodiaceae		*Phlegmariurus varius*	(R.Br.) A.R. Field & Bostock	Long Clubmoss
Class Filicopsida - Ferns				
Aspleniaceae		*Asplenium goudeyi*	D.L.Jones	
Aspleniaceae		*Asplenium milnei*	Carruth.	
Aspleniaceae		*Asplenium surrogatum*	P.S.Green	
Aspleniaceae		*Asplenium polyodon*	G.Forst.	Sickle Spleenwort
Athyriaceae		*Diplazium melanochlamys*	(Hook.) T.Moore	
Blechnaceae		*Blechnum contiguum*	Mett.	
Blechnaceae		*Blechnum howeanum*	T.C.Chambers & P.A.Farrant	
Blechnaceae		*Blechnum patersonii* subsp. *patersonii*	(R.Br.) Mett.	Strap Water Fern
Blechnaceae		*Doodia caudata*	(Cav.) R.Br.	Rasp Fern
Cyatheaceae		*Cyathea brevipinna*	Baker ex Benth.	Tree Fern
Cyatheaceae		*Cyathea howeana*	Domin	Tree Fern
Cyatheaceae		*Cyathea macarthurii*	(F.Muell.) Baker	Tree Fern
Cyatheaceae		*Cyathea robusta*	(C.Moore) Holttum	Tree Fern
Dryopteridaceae		*Lastreopsis nephrodioides*	(Baker) Tindale	
Dryopteridaceae		*Polystichum whiteleggei*	Watts	
Hymenophyllaceae		*Cephalomanes bauerianum*	(Endl.) P.S.Green	
Hymenophyllaceae		*Hymenophyllum howense*	Brownlie	
Lomariopsidaceae		*Nephrolepis cordifolia*	(L.) Presl	Fishbone Fern
Ophioglossaceae		*Ophioglossum pendulum*	L.	Ribbon Fern
Polypodiaceae		*Grammitis nudicarpa*	Copel.	
Polypodiaceae		*Grammitis wattsii*	Copel.	
Polypodiaceae		*Microsorum pustulatum* subsp. *howense*	(Tindale & P.S.Green) Bostock	Kangaroo Fern
Polypodiaceae		*Microsorum scandens*	(G.Forst.) Tindale	Fragrant Fern
Polypodiaceae		*Pyrrosia confluens* var. *confluens*	(R.Br.) Ching	Horseshoe Felt Fern
Polypodiaceae		*Platycerium bifurcatum*	(Cav.) C.Chr.	Elkhorn
Psilotaceae		*Tmesipteris truncata*	(R.Br.) Desv.	
Psilotaceae		*Psilotum nudum*	(L.) P.Beauv.	Skeleton Fork-fern
Pteridaceae		*Adiantum hispidulum*	Sw.	Rough Maidenhair Fern
Pteridaceae		*Pellaea paradoxa*	(R.Br.) Hook.	Sickle Fern
Pteridaceae		*Pteris microptera*	Mett. ex Kuhn	
Tectariaceae		*Arthropteris tenella*	(G.Forst.) J.Sm. ex Hook.f.	
Thelypteridaceae		*Cyclosorus dentatus*	(Forssk.) Ching	
Class Coniferopsida - Conifers				
Araucariaceae	*	*Araucaria heterophylla*	(Salisb.) Franco	Norfolk Island Pine
Class Magnoliopsida - Magnoliidae				
Acanthaceae		*Avicennia marina* subsp. *australasica*	(Walp.) J.Everett	Grey Mangrove
Aizoaceae		*Sesuvium portulacastrum*	L.	Ice Plant
Aizoaceae		*Tetragonia tetragonioides*	(Pall.) Kuntze	Native Spinach
Amaranthaceae		*Achyranthes aspera*	L.	Chaff Flower
Apiaceae		*Apium prostratum* subsp. *howense*	P.S.Short	Sea Celery
Apiaceae	*	*Cyclospermum leptophyllum*	(Pers.) Sprague ex Britton & P.Wilson	Slender Celery

Class / Family	**Status**	**Scientific name**	**Authority**	**Common name**
Apiaceae	*	*Hydrocotyle bonariensis*	Lam.	Kurnell Curse
Apiaceae		*Hydrocotyle hirta*	A.Rich. ex R.Br.	Hairy Pennywort
Apiaceae	*	*Torilis nodosa*	(L.) Gaertn.	Knotted Hedge-parsley
Apocynaceae		*Alyxia ruscifolia*	R.Br.	Christmas Bush
Apocynaceae		*Alyxia squamulosa*	C.Moore & F.Muell.	Climbing Fishbone Fern
Apocynaceae		*Marsdenia rostrata*	R.Br.	Common Milk Vine
Apocynaceae		*Tylophora biglandulosa*	(Endl.) F.Muell.	
Apocynaceae		*Ochrosia elliptica*	Labill.	Red Berrywood
Apocynaceae		*Parsonsia howeana*	J.B.Williams	
Araliaceae		*Polyscias cissodendron*	(C.Moore & F.Muell.) Harms	Island Pine
Asteraceae		*Actites megalocarpus*	(Hook. f.) Lander	Dune Thistle
Asteraceae	*	*Ageratina adenophora*	(Spreng.) R.M.King & H.Rob.	Crofton Weed
Asteraceae	*	*Aster subulatus*	Michx.	Wild Aster
Asteraceae	*	*Bidens pilosa*	L.	Cobbler's Pegs
Asteraceae		*Brachyscome segmentosa*	C.Moore & F.Muell.	Lord Howe Island Daisy
Asteraceae		*Cassinia tenuifolia*	Benth.	Bully Bush
Asteraceae	*	*Cirsium vulgare*	(Savi) Ten.	Spear Thistle
Asteraceae	*	*Conyza parva*	Cronquist	
Asteraceae		*Cotula australis*	(Sieber ex Spreng.) Hook.f.	Carrot Weed
Asteraceae		*Euchiton involucratus*	(G.Forst.) Holub	
Asteraceae	*	*Hypochaeris radicata*	L.	Catsear
Asteraceae		*Lordhowea insularis*	(Benth.) B.Nord.	
Asteraceae		*Melanthera biflora*	(L.) Wild	
Asteraceae		*Olearia ballii*	(F.Muell.) Hemsl.	Mountain Daisy
Asteraceae		*Olearia mooneyi*	(F.Muell.) Hemsl.	Pumpkin Bush
Asteraceae	*	*Senecio elegans*	L.	Purple Groundsel
Asteraceae		*Senecio howeanus*	Belcher	
Asteraceae	*	*Sonchus oleraceus*	L.	Sow Thistle
Asteraceae	*	*Taraxacum officinale*	Weber	Dandelion
Bignoniaceae		*Pandorea pandorana* subsp. *austrocaledonica*	(Bureau) P.S.Green	Boat Vine
Brassicaceae	*	*Cakile edentula*	(Bigelow) Hook.	American Sea Rocket
Brassicaceae		*Lepidium howei-insulae*	Thell.	Mustard & Cress
Brassicaceae	*	*Lobularia maritima*	(L.) Desv.	Sweet Alyssum
Campanulaceae		*Wahlenbergia insulae-howei*	Lothian	
Cannabaceae		*Celtis conferta* subsp. *amblyphylla*	(F.Muell.) P.S.Green	Cotton-wood
Caryophyllaceae	*	*Cerastium glomeratum*	Thuill.	Mouse-ear Chickweed
Celastraceae		*Elaeodendron curtipendulum*	Endl.	Tamana
Chenopodiaceae		*Atriplex cinerea*	Poir.	Grey Saltbush
Chenopodiaceae		*Carpobrotus glaucescens*	(Haw.) Schwantes	Pigface
Chenopodiaceae	*	*Chenopodium murale*	L.	Nettle-leaf Goosefoot
Convolvulaceae		*Ipomoea brasiliensis*	(L.) Sweet	Beach Bean
Convolvulaceae	*	*Ipomoea cairica*	(L.) Sweet	Coastal Morning Glory
Convolvulaceae		*Calystegia soldanella*	(L.) Roem. & Schult.	
Crassulaceae		*Crassula sieberiana*	(Schult. & Schult.f.) Druce	Australian Stonecrop
Elaeocarpaceae		*Elaeocarpus costatus*	M.Taylor	
Ericaceae		*Dracophyllum fitzgeraldii*	C.Moore & F.Muell.	Fitzgerald
Ericaceae		*Leucopogon parviflorus*	(Andrews) Lindl.	
Euphorbiaceae	*	*Euphorbia cyathophora*	Murray	Painted Spurge
Euphorbiaceae	*	*Euphorbia paralias*	L.	Sea Spurge
Euphorbiaceae		*Homalanthus populifolius*	Graham	Bleeding Heart
Euphorbiaceae		*Baloghia inophylla*	(G.Forst.) P.S.Green	Brush Bloodwood
Fabaceae		*Canavalia rosea*	(Sw.) DC.	Coastal Jack Bean

Class / Family	**Status**	**Scientific name**	**Authority**	**Common name**
Fabaceae	*	*Melilotus indicus*	(L.) All.	King Island Melilot
Fabaceae		*Mucuna gigantea* subsp. *gigantea*	(Willd.) DC.	Burny Bean
Fabaceae	*	*Vicia sativa*	L.	Common Vetch
Fabaceae		*Sophora howinsula*	(W.R.B.Oliv.) P.S.Green	Lignum Vitae
Fabaceae		*Vigna marina*	(Burm.) Merr.	Dune Bean
Flacourtiaceae		*Xylosma maidenii*	Sleumer	
Flacourtiaceae	BC-E	*Xylosma parvifolia*	Jessup	Mountain Xylosma
Gesneriaceae		*Negria rhabdothamnoides*	F.Muell.	Pumpkin Tree
Lamiaceae		*Westringia viminalis*	B.J.Conn & M.E.Tozer	
Lauraceae		*Cryptocarya gregsonii*	Maiden	Black Plum
Lauraceae		*Cryptocarya triplinervis* var. *triplinervis*	R.Br.	Blackbutt
Lobeliaceae		*Lobelia anceps*	L.f.	
Loganiaceae	BC-E	*Geniostoma huttonii*	B.J.Conn	
Loganiaceae		*Geniostoma petiolosum*	C.Moore & F.Muell.	Boar Tree
Malvaceae		*Hibiscus tiliaceus*	L.	Cottonwood Hibiscus
Malvaceae		*Lagunaria patersonia* subsp. *patersonia*	(Andrews) G.Don	Sallywood
Meliaceae		*Dysoxylum pachyphyllum*	Hemsl.	Island Apple
Menispermaceae		*Stephania japonica* var. *timoriensis*	(DC.) Forman	Snake Vine
Moraceae		*Ficus macrophylla* subsp. *columnaris*	(C.Moore) D.J.Dixon	Banyan
Moraceae		*Trophis scandens* subsp. *megacarpa*	(P.S.Green) P.S.Green	Burny Vine
Myrsinaceae		*Aegiceras corniculatum*	(L.) Blanco	River Mangrove
Myrtaceae		*Leptospermum polygalifolium* subsp. *howense*	Joy Thomps.	
Myrtaceae		*Melaleuca howeana*	Cheel	Tea Tree
Myrtaceae		*Metrosideros nervulosa*	C.Moore & F.Muell.	Mountain Rose
Myrtaceae		*Metrosideros sclerocarpa*	J.W.Dawson	Hill Rose
Myrtaceae	*	*Psidium cattleyanum* var. *cattleyanum*	Sabine	Cherry Guava
Myrtaceae		*Syzygium fullagarii*	(F.Muell.) Craven	Scalybark
Nyctaginaceae		*Pisonia brunoniana*	Endl.	Punkwood
Oleaceae		*Jasminum didymum* subsp. *didymum*	G.Forst.	Jasmine
Oleaceae		*Jasminum volubile*	Jacq.	Stiff Jasmine
Oleaceae		*Olea paniculata*	L.	Maulwood
Oleaceae		*Chionanthus quadristamineus*	F.Muell.	Blue Plum
Onagraceae	*	*Oenothera tetraptera*	Cav.	
Oxalidaceae	*	*Oxalis corniculata*	L.	
Oxalidaceae		*Oxalis rubens*	Haw.	
Piperaceae		*Macropiper excelsum* subsp. *psittacorum*	(Endl.) Sykes	Kava
Piperaceae		*Macropiper hooglandii*	I.Hutton & P.S.Green	Kava
Piperaceae		*Peperomia tetraphylla*	(G.Forst.) Hook. & Arn.	Four-leaved Pepper Plant
Piperaceae		*Peperomia urvilleana*	A.Rich.	
Pittosporaceae		*Pittosporum erioloma*	C.Moore & F.Muell.	Hedge Laurel
Pittosporaceae	*	*Pittosporum undulatum*	Vent.	Snowdrop Tree
Plantaginaceae	*	*Plantago lanceolata*	L.	Plantain
Polygonaceae		*Muehlenbeckia complexa*	(A.Cunn.) Meisn.	Wire Vine
Polygonaceae		*Rumex brownii*	Campd.	Swamp Dock
Portulacaceae		*Portulaca oleracea*	L.	Purslane
Primulaceae		*Myrsine mccomishii*	(Sprague) Jackes	
Primulaceae		*Myrsine platystigma*	F.Muell.	
Putranjivaceae		*Drypetes deplanchei*	(Brongn. & Gris) Merr.	Greybark
Ranunculaceae		*Clematis glycinoides*	DC.	Headache Vine
Rosaceae	*	*Potentilla indica*	(Jacks.) Th.Wolf	Indian Strawberry
Rubiaceae		*Atractocarpus stipularis*	(F.Muell.) Puttock	Green Plum
Rubiaceae		*Psychotria carronis*	C.Moore & F.Muell.	Black Grape
Rubiaceae	*	*Richardia spp.*		

Class / Family	**Status**	**Scientific name**	**Authority**	**Common name**
Rubiaceae		*Coprosma huttoniana*	P.S.Green	
Rubiaceae		*Coprosma lanceolaris*	F.Muell.	
Rubiaceae		*Coprosma prisca*	W.R.B.Oliv.	Goatwood
Rubiaceae		*Coprosma putida*	C.Moore & F.Muell.	Stinkwood
Rubiaceae		*Coprosma sp. nov*		
Rutaceae		*Melicope contermina*	C.Moore & F.Muell.	
Rutaceae		*Melicope polybotrya*	(C.Moore & F.Muell.) T.G.Hartley	
Rutaceae		*Sarcomelicope simplicifolia* subsp. *simplicifolia*	(Endl.) T.G.Hartley	Yellow Wood
Rutaceae		*Zanthoxylum pinnatum*	(J.R.Forst. & G.Forst.) W.R.B.Oliv.	Yellow Wood
Santalaceae		*Exocarpos homalocladus*	C.Moore & F.Muell.	Grass Tree
Sapindaceae		*Dodonaea viscosa* subsp. *burmanniana*	(DC.) J.G.West	Hop Bush
Sapindaceae		*Guioa coriacea*	(Radlk.) Radlk.	Cedar
Sapotaceae		*Planchonella howeana*	(F.Muell.) Pierre	
Scrophulariaceae		*Myoporum insulare*	R.Br.	Boobialla
Solanaceae		*Nicotiana forsteri*	Roem. & Schult.	
Solanaceae	*	*Physalis ixocarpa*	Brot. ex Hornem.	Ground Cherry
Solanaceae	*	*Solanum nigrum*	L.	Blackberry Nightshade
Symplocaceae		*Symplocos candelabrum*	Brand	
Thymelaeaceae		*Pimelea congesta*	C.Moore & F.Muell.	
Urticaceae		*Parietaria debilis*	G.Forst.	Native Pellitory
Urticaceae	*	*Parietaria judaica*	L.	Pellitory
Urticaceae		*Elatostema reticulatum*	Wedd.	Rainforest Spinach
Viscaceae		*Korthalsella rubra*	(Tiegh.) Engl.	Jointed Mistletoe
Winteraceae		*Bubbia howeana*	(F.Muell.) Tieg.	Hotbark
Class Magnoliopsida - Liliidae				
Amaryllidaceae		*Crinum pedunculatum*	R.Br.	River Lily
Arecaceae		*Hedyscepe canterburyana*	(C.Moore & F.Muell.) H.Wendl. & Drude	Big Mountain Palm
Arecaceae		*Howea belmoreana*	(C.Moore & F.Muell.) Becc.	Curly Palm
Arecaceae		*Howea forsteriana*	(C.Moore & F.Muell.) Becc.	Kentia Palm
Arecaceae	BC-E	*Lepidorrhachis mooreana*	(F.Muell.) O.F.Cook	Little Mountain Palm
Asparagaceae	*	*Asparagus aethiopicus*	L.	Ground Asparagus
Asparagaceae	*	*Asparagus plumosus*	Baker	Climbing Asparagus
Commelinaceae		*Commelina cyanea*	R.Br.	Native Wandering Jew
Cyperaceae		*Carex breviculmis*	R.Br.	
Cyperaceae		*Carex brunnea*	Thunb.	Greater Brown Sedge
Cyperaceae		*Cyperus lucidus*	R.Br.	Leafy Flat Sedge
Cyperaceae		*Ficinia nodosa*	(Rottb.) Goetgh., Muasya & D.A.Simpson	Club Rush
Cyperaceae		*Gahnia howeana*	R.O.Gardner	
Cyperaceae		*Machaerina insularis*	(Benth.) T.Koyama	
Flagellariaceae		*Flagellaria indica*	L.	Whip Vine
Iridaceae		*Dietes robinsoniana*	(C.Moore & F.Muell.) Klatt	Lord Howe Wedding Lily
Juncaceae		*Luzula longiflora*	Benth.	
Juncaginaceae		*Triglochin striata*	Ruiz & Pav.	Water Ribbons
Liliaceae	*	*Lilium formosanum*	A.Wallace	Formosan Lily
Luzuriagaceae		*Geitonoplesium cymosum*	(R.Br.) A.Cunn. ex Hook.	Scrambling Lily
Orchidaceae		*Calanthe triplicata*	(Willemet) Ames	Christmas Orchid
Orchidaceae		*Corybas spp.*		
Orchidaceae		*Dendrobium gracilicaule* var. *howeanum*	Maiden	
Orchidaceae		*Dendrobium moorei*	F.Muell.	
Orchidaceae		*Pterostylis curta*	R.Br.	
Orchidaceae		*Pterostylis spp.*		

Class / Family	**Status**	**Scientific name**	**Authority**	**Common name**
Pandanaceae		*Pandanus forsteri*	C.Moore & F.Muell.	Forky-tree
Phormiaceae		*Dianella intermedia*	Endl.	Flax Lily
Poaceae	*	*Bromus catharticus*	Vahl	Prairie Grass
Poaceae	*	*Cenchrus clandestinus*	(Hochst. ex Chiov.) Morrone	Kikuyu
Poaceae	*	*Chloris gayana*	Kunth	Rhodes Grass
Poaceae		*Cynodon dactylon*	(L.) Pers.	Blue Couch
Poaceae	*	*Digitaria ciliaris*	(Retz.) Koeler	Summer Grass
Poaceae		*Echinopogon caespitosus* var. *caespitosus*	C.E.Hubb.	Hedgehog Grass
Poaceae	*	*Ehrharta erecta*	Lam.	Panic Veldtgrass
Poaceae	*	*Melinis minutiflora*	P.Beauv.	Molasses Grass
Poaceae		*Microlaena stipoides* var. *stipoides*	(Labill.) R.Br.	Weeping Meadow Grass
Poaceae		*Oplismenus imbecillis*	(R.Br.) Roem. & Schult.	Creeping Beard Grass
Poaceae	*	*Paspalum dilatatum*	Poir.	Paspalum
Poaceae	*	*Paspalum mandiocanum*	Trin.	Broadleaf Paspalum
Poaceae		*Phragmites australis*	(Cav.) Trin. ex Steud.	Native Reed
Poaceae	*	*Poa annua*	L.	Winter Grass
Poaceae		*Poa poiformis* var. *poiformis*	(Labill.) Druce	Coast Tussock Grass
Poaceae		*Spinifex sericeus*	R.Br.	Spinifex
Poaceae	*	*Sporobolus africanus*	(Poir.) Robyns & Tournay	Parramatta Grass
Poaceae		*Sporobolus virginicus* var. *virginicus*	(L.) Kunth	Saltwater Couch
Poaceae	*	*Stenotaphrum secundatum*	(Walter) Kuntze	Buffalo Grass
Smilacaceae		*Smilax australis*	R.Br.	Lawyer Vine

Date of Publication:
April 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

A simple method to collect viable rainforest tree seeds and study the frugivorous diet of satin bowerbirds (*Ptilonorhynchus violaceus*)

Barry Hicks[1] *and Todd F. Elliott*[2,*]

[1]248 Blue Rock Road, Dundurrabin, NSW 2453; [2]Ecosystem Management,
School of Environmental and Rural Science, University of New England, Armidale, NSW 2351;
[*]Corresponding author: toddfelliott@gmail.com

Abstract: For more than 100 years, behavioural biologists have extensively studied satin bowerbirds (*Ptilonorhynchus violaceus*) to understand the complexities of bower construction and courtship, but this research has not accounted for the ecologically important role the species plays as a seed disperser in eastern Australia. In this study, we have used a simple method involving pans of water and mirrors to collect scats from male satin bowerbirds on the Dorrigo Plateau of northeastern New South Wales. Based on seeds identified from scats collected using this method, we identify the fruits of 37 plant species in 22 families that are eaten by satin bowerbirds and show that 35 of these species germinated after passage through the digestive system of bowerbirds. This method was developed for bush regenerators to collect rainforest tree seeds that are otherwise inaccessible and/or difficult to germinate; it is applicable throughout the range of satin bowerbirds. We hope the method will be adopted by bush regenerators for harvesting seeds otherwise difficult to source, and by ornithologists studying the diets and seed dispersal of these ecologically significant birds.

Keywords: Avian seed dispersal, frugivore, rainforest trees, bowerbirds, bush regeneration

***Cunninghamia* (2020) 20: 099–104**
doi: 10.7751/cunninghamia.2020.20.003

© 2020 Royal Botanic Gardens and Domain Trust

Introduction and Methods

Bowerbirds are only found in Australia and New Guinea, and for more than a century, they have been the subject of many studies of sexual selection (Darwin, 1888; Chisholm, 1924; Gilliard, 1969; Borgia, 1986, 1995; Frith & Frith, 2004; Hansell, 2007). Most species feed heavily on fruit and other plant material (leaves, flowers and/or buds) and will also include insects in their diet (Gilliard, 1969; Pruett-Jones & Pruett-Jones 1982; Pratt & Stiles, 1983; Diamond, 1986; Moore, 1991; Frith, 1995; Eddie, 2001; Borgia & Keagy 2006; Frith & Frith, 2016). These species may in turn be acting as seed dispersers. Some bowerbirds also incidentally disperse and/or cultivate plants or fungi that they use as bower decorations (Madden et al., 2012; Elliott & Marshall, 2016; Elliott et al., 2019).

Satin bowerbirds (*Ptilonorhynchus violaceus*) have a nearly 3,000 km range from northern Queensland to southern Victoria, and are among the most common, adaptable and best studied bowerbird species (Gilliard, 1969). They are noted to steal fruit from orchards, as well as eat a diversity of insects, wild fruits and leaves (Cole, 1910; Marshall, 1932; Chaffer, 1945; Gilliard, 1969; Diamond, 1986; Green, 1993). Despite their large range and abundance, there has been limited research into their diets, their role as seed dispersers, what species they actually ingest and whether or not the seeds of these species remain viable. Apart from a study reporting 11 fruit species eaten by satin bowerbirds in and around Lamington and Border Ranges National Parks in northeastern NSW (Green, 1993) and the chance observations by Marshall (1932) of satin bowerbirds eating four fruit species in the Sydney region, we were unable to locate previous research that directly studied the diversity of species eaten and/or tested the viability of seeds post-ingestion.

The objective of this study was to find a practical way to collect viable rainforest tree seeds for bush regeneration efforts; it was not designed as an ecological study, but it represents two decades of careful observation of satin bowerbirds and experimentation with methods of seed collection by the first author. Through trial and error, it became apparent that the technique we outline is simple yet highly effective for seed collection and provides data that we hope will be useful to bush regenerators, botanists and ecologists. We think this method could also be used more systematically by ornithologists to study the ecological significance of frugivory by satin bowerbirds and their role in seed dispersal.

To collect scats for this study, shallow tubs containing 30-100 mm water were placed at the edges of small clearings adjacent to undisturbed subtropical rainforest in areas known to be visited by satin bowerbirds (Figure 1). Two sites were used for this study; both were located on private property off of Blue Rock Road and Chaelundi Road near Dundurrabin, NSW. These areas were known to be used by bowerbirds but were not necessarily close to bowers or nest sites. For approximately 20 years, two tubs were put out at two different locations and left to collect scats during the spring, summer and autumn fruiting periods. A handheld or vanity mirror was placed vertically at one end of each tub of water (approximately 200 mm away from the edge of the tub). We observed male satin bowerbirds regularly visiting these stations, perching and 'dancing' in front of the mirror and depositing scats in the water in the process. Scats were removed from the tubs of water within three days of being deposited by birds. The scats were identified as bowerbird scats by close observation of which birds were visiting these stations. It is important to point out that this approach only attracts mature and nearly mature male satin bowerbirds (Figure 1). It is much harder to attract females or juvenile males, but they are more likely to visit a baited location. An effective way to collect their scats is to lay a flat piece of cardboard down (to make it easier to find scats) and stake an apple in the middle. The bowerbird will eat the apple and deposit scats on the cardboard while it eats, but the scats dry out quickly and this set-up has to be checked more regularly than using a tub of water. The data in this study is based on male satin bowerbirds. Though we have frequently observed satin bowerbirds foraging in mixed sex flocks and suspect that females and juvenile males are equally important seed dispersers, we do not have scat data to support this hypothesis.

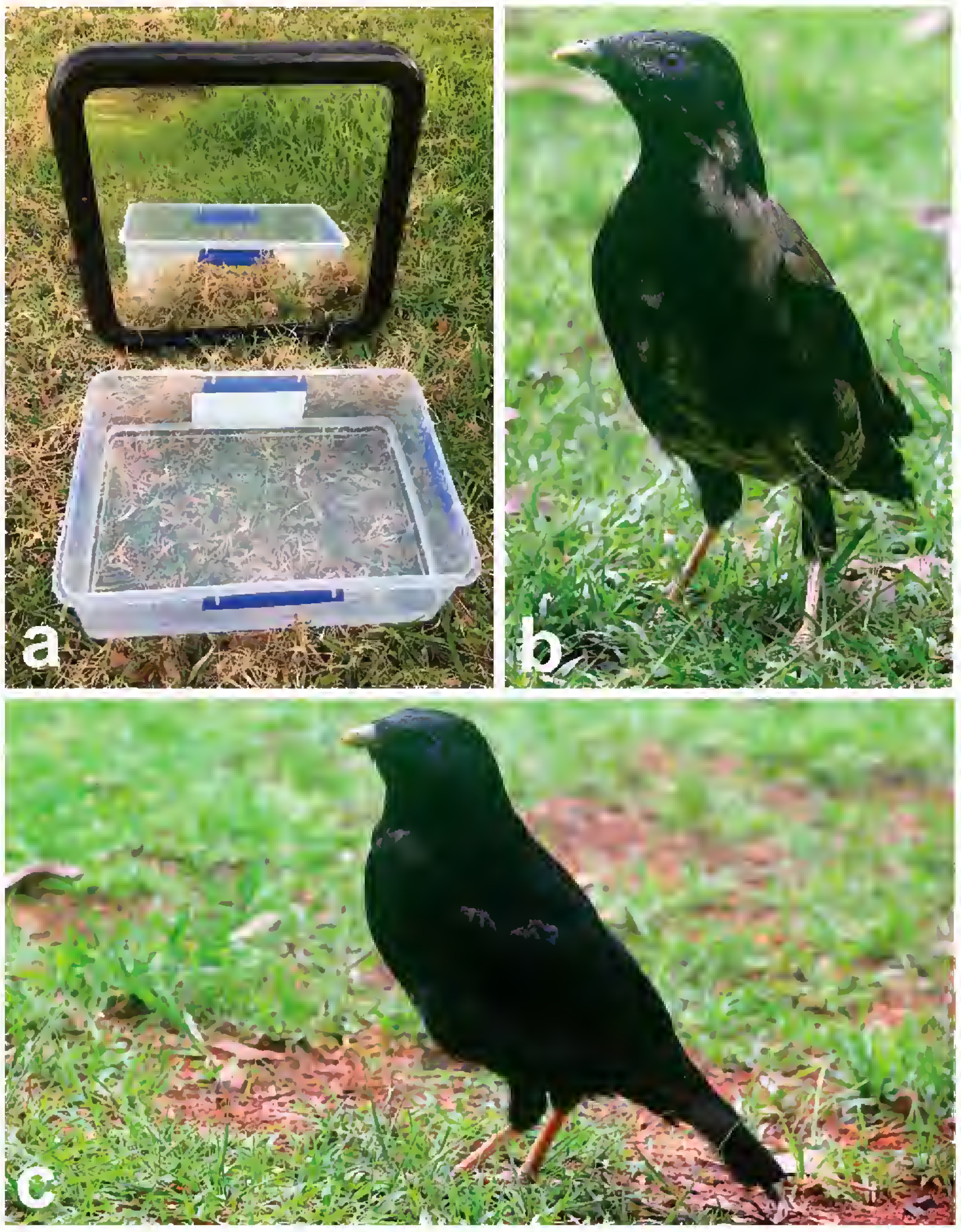


Figure 1: a An example of the simple set-up used in this study to collect scats. It requires a mirror to be placed in front of a shallow tub of water with enough room for the male bowerbird to perch and interact with his reflection while depositing scats in the tub of water. These scats were later collected, washed and sown into potting mix. **b** A nearly mature male with the mottled pattern that develops as he moults into his adult male plumage. Nearly mature males such as this one occasionally visited our stations, but not as frequently as adult males. **c** An adult male in full adult plumage. These males were the primary users of these stations.

The scats were removed from the tubs and the seeds cleaned with water and identified to species before being sown in potting mix. We have been unable to find a comprehensive identification reference for seeds of our region; seeds were identified based on previous experience with seeds found in the surrounding area, and any ambiguous identifications were confirmed once the seedlings germinated and began to grow. Several potting mixes were used, and the composition of the mix varied substantially depending on what was available (all mixes had previously proven successful in germinating and growing rainforest trees from the same area). Seeds were sown in a range of pot sizes placed in shade houses, and all pots were watered as needed. Notes were taken on which species successfully germinated. All successfully germinated trees were eventually planted as part of forest regeneration efforts in the surrounding area.

Results and Discussion

Based on approximately 2,500 scats, we found the fruits of 37 plant species representing 22 families to be eaten by satin bowerbirds (Table 1). Both sites where tubs were placed are adjacent to large intact areas of native bush with very few weed species, so we did not determine if satin bowerbirds might disperse weeds. It is possible that they may eat and disperse common non-natives such as *Cinnamomum camphora* or *Ligustrum lucidum*, but these species were absent from the locations we sampled. Bush regenerators who might try to apply this method should be aware of the areas where bowerbird scats are sourced, since the species composition of their habitat directly impacts the species that occur in their diets and scats. Only once during the course of this study were seeds of a non-native plant encountered in a scat; these were *Asparagus officinalis* seeds that were being cultivated in the first author's nearby vegetable garden. This instance was not included in the study.

Of the 37 species detected in scats in this study, all but two taxa (*Persoonia media* and *Trochocarpa laurina*) germinated. We have been unable to successfully germinate these two species regardless of seed source (even when ripe fruit was collected directly from the plant). These two genera are known to have dormant seed that can be difficult and/or slow to germinate (Campbell et al. 2012; Emery & Offord 2018; Emery & Offord 2019), so the lack of germination may just indicate that dormancy was not relieved by passage through the bowerbird gut. We were primarily focused on woody plants for regeneration efforts, so we have possibly overlooked herbaceous plants that might be ingested and dispersed by satin bowerbirds.

Since this study was focused on developing a method to collect viable seeds, we were interested in determining which plant species were being eaten by the birds and which species were viable after passage through the gut. We did not collect data to compare germination rates or percentages of seeds that were ingested versus seeds that were hand-collected. Based on experience of germinating these species from hand-collected seeds, we can highlight four tree species that appear to germinate more readily after being consumed by satin bowerbirds; however, additional study is still needed for further confirmation. *Elaeocarpus reticulatus* and the three *Polyscias* species, *Polyscias elegans*, *Polyscias murrayi* and *Polyscias sambucifolia* (Table 1), generally have comparatively low germination rates when seeds are harvested directly from the plant, but germination success is much higher when seeds are collected from satin bowerbird scats. *Dysoxylum fraserianum* and *Synoum glandulosum* also appear to have better germination rates when seeds are collected from satin bowerbird scats compared to seeds collected and cleaned by hand. For successful germination of many plants, it is important to clean off the fleshy coatings around the seeds (Mirov & Kraebel, 1939; Broschat & Donselman, 1987). Cleaning seeds of some rainforest trees can lead to accidental damage of seed coats (particularly in these two species), which reduces their viability. The difference we noticed in their germination from scats may be a result of collecting and processing methods rather than gut scarification.

Satin bowerbirds appear to primarily collect ripe fruit; scats therefore tend to have good material for propagation. When collecting seeds from *Myrsine howittiana* and *Myrsine variabilis* plants, it is difficult to determine which individual fruits are actually ripe, and germination rates tend to be low. Seeds collected from scats generally appear to have better germination rates, perhaps due to the fact that satin bowerbirds seem to choose the ripest fruit, and/or the seeds may benefit from scarification.

Schizomeria ovata is notoriously slow and difficult to germinate; Floyd (2008) reports its germination to be very erratic, sometimes taking up to nine years. It seems possible that this lengthy period of germination could be due to a lack of scarification by a frugivore, but in this study it took up to 18 months to germinate regardless of where the seeds were sourced (after 18 months, pots with ungerminated seeds were discarded due to limited shade house space). Based on our observations, it seems unlikely that bowerbirds improve *Schizomeria* germination rates. Floyd (2008) recommends cuttings as a more successful method to grow this species.

The seeds of many plants eaten by satin bowerbirds are easy to harvest and germinate without collecting them from bowerbird scats, but it can be difficult to collect fruit or seeds from the larger rainforest trees that fruit high up in the canopy, like *Citronella moorei*, *Diospyros pentamera* and *Sarcopteryx stipata*. Since satin bowerbirds feed on the ripe fruit and inadvertently carry seeds, their scats are an ideal source of viable seeds for these and other tall rainforest trees. We would struggle to source seeds from these species without the help of bowerbirds.

Based on observations of satin bowerbird feeding behaviour, Green (1993) reported 11 species of fruit in eight families as food sources, including four that we observed and seven species that we did not (Table 1); she did not test seed viability. Marshall (1932) observed satin bowerbirds feeding on four species in three families that were not recorded elsewhere, but he did not test germination. Without attempting to germinate the seeds, we can only speculate about the viability of these additional 11 species. But based on the combined data in these three studies, it is apparent that fruit of at least 48 plant species in 27 families are food sources for satin bowerbirds; some benefit from enhanced germination, and most species—or possibly all—benefit from seed dispersal.

Table 1: The 48 plant species in 27 families known to be eaten by satin bowerbirds (*Ptilonorhynchus violaceus*) and their viability from scats.

Viable column: **Yes** = viable in germination tests performed in this study; **No** = failed to germinate in this study; **Not found** = not found in the scats of birds sampled in this study.

Other Records: Marshall = observed by A. J. Marshall to be eaten in the Sydney region. **Green** = observed by R. J. Green to be eaten in and around Lamington and Border Ranges National Parks in northeastern New South Wales.

**Ficus muelleriana* (South Coast Fig) is a name used in Marshall (1932) for a fig supposedly eaten in the Kiama District of NSW. To the best of our knowledge, this species name is misapplied unless Marshall is reporting consumption of the fruit of an introduced African species.

Family	Species (common name)	Viable	Other Records
Araliaceae	*Polyscias elegans* (Celery Wood)	Yes	
	Polyscias murrayi (Pencil Cedar)	Yes	
	Polyscias sambucifolia (Elderberry Panax)	Yes	
Arecaceae	*Linospadix monostachyos* (Walking Stick Palm)	Yes	
Asteliaceae	*Cordyline stricta* (Narrow-leaved Palm Lily)	Yes	
Boraginaceae	*Ehretia acuminata* (Koda)	Not found	Green
Cardiopteridaceae	*Citronella moorei* (Churnwood/Soapy Box)	Yes	
Cunoniaceae	*Schizomeria ovata* (Crabapple)	Yes	
Dilleniaceae	*Hibbertia scandens* (Yellow Guinea Flower)	Yes	
Ebenaceae	*Diospyros australis* (Black Plum)	Yes	
	Diospyros pentamera (Myrtle Ebony)	Yes	Green
Elaeocarpaceae	*Elaeocarpus obovatus* (Hard Quandong)	Not found	Green
	Elaeocarpus reticulatus (Blueberry Ash)	Yes	
	Sloanea woollsii (Yellow Carabeen)	Yes	
Ericaceae	*Trochocarpa laurina*	No	
Eupomatiaceae	*Eupomatia laurina* (Bolwarra)	Yes	
Fabaceae	*Acacia binervata* (Two-veined Hickory)	Yes	
	Acacia melanoxylon (Blackwood)	Yes	
Lamiaceae	*Vitex lignum-vitae* (Yellow Hollywood)	Not found	Green
Lauraceae	*Cryptocarya foveolata* (Mountain Walnut)	Yes	
	Cryptocarya glaucescens (Jackwood)	Yes	
	Cryptocarya meisneriana (Thick-leaved Laurel)	Yes	
	Cryptocarya rigida (Forest Maple)	Yes	
Meliaceae	*Dysoxylum fraserianum* (Rosewood)	Yes	
	Synoum glandulosum (Scentless Rosewood)	Yes	
Moraceae	*Ficus macrophylla* (Moreton Bay Fig)	Not found	Green
	**Ficus muelleriana* (South Coast Fig)	Not found	Marshall
	Ficus rubiginosa (Port Jackson Fig)	Not found	Marshall
	Ficus superba (Deciduous Fig)	Not found	Green
	Ficus watkinsiana (Strangling Fig)	Not found	Green
Myrtaceae	*Acmena ingens* (Red Apple)	Not found	Green
	Acmena smithii (Creek Lilly Pilly)	Yes	Green
	Archirhodomyrtus beckleri (Rose Myrtle)	Yes	
	Syzygium australe (Brush Cherry)	Yes	
Primulaceae	*Myrsine howittiana* (Brush Muttonwood)	Yes	
	Myrsine variabilis (Muttonwood)	Yes	
Proteaceae	*Persoonia media*	No	
Ripogonaceae	*Ripogonum discolor* (Prickly Supplejack)	Yes	
Rosaceae	*Rubus* sp. (Wild Raspberry)	Not found	Marshall
Rubiaceae	*Psychotria loniceroides* (Hairy Psychotria)	Yes	
Rutaceae	*Acronychia oblongifolia* (White Aspen)	Yes	Green

Family	Species (common name)	Viable	Other Records
Sapindaceae	*Alectryon subcinereus* (Bird's Eye)	Yes	
	Diploglottis australis (Native Tamarind)	Yes	Green
	Guioa semiglauca (Guioa)	Yes	
	Sarcopteryx stipata (Steelwood/Corduroy)	Yes	
Sapotaceae	*Planchonella australis* (Black Apple)	Not found	Marshall
Trimeniaceae	*Trimenia moorei* (Bitter Vine)	Yes	
Vitaceae	*Cissus hypoglauca* (Five-leaved Water Vine)	Yes	

Though we did not systematically observe what plant species were predominant in the satin bowerbird diets, this study highlights the reliance of this bird on a diverse fruit-bearing plant community. On the Dorrigo Plateau, in years of heavy fruit set by *Elaeocarpus reticulatus*, it was apparent that this fruit was a preferred food and often formed a high percentage of satin bowerbird diets. We have observed topknot pigeons (*Lopholaimus antarcticus*) eating the fruit and possibly dispersing the seeds of *Acronychia oblongifolia*, *Cissus hypoglauca* and *Schizomeria ovata*; however, we have not tested seed viability after consumption by topknot pigeons. We have also observed brown cuckoo-doves (*Macropygia phasianella*) and Lewin's honeyeaters (*Meliphaga lewinii*) regularly eating the fruit of *Archirhodomyrtus beckleri,* but we have yet to test the viability of these seeds. Other frugivorous bird species are undoubtedly important seed dispersers in the region, but we have been unable to develop a way to attract them and consistently collect their scats.

We suspect that other members of the Ptilonorhynchidae may also be important seed dispersers in Australia and New Guinea. In far north Queensland, for example, 51 species of seeds were found in the scats of the tooth-billed bowerbird (*Scenopoeetes dentirostris*), many of which germinated from the scats (Moore, 1991). According to Moore, tooth-billed bowerbirds frequently visited and deposited seeds in areas that had been logged. We have observed that satin bowerbirds frequently flock in or around small clearings or disturbed sites; they are likely functioning similarly to tooth-billed bowerbirds by bringing seeds of many rainforest species into these disturbed areas, helping to reforest disturbed landscapes.

This study focused on a relatively small region, but many of the plant species and/or genera consumed and dispersed by satin bowerbirds are more widely distributed. Approximately two thirds of the trees in northeastern New South Wales and southeastern Queensland produce fleshy fruit (Williams et al., 1984). These fleshy fruits are ideally adapted for avian dispersal, and although many of them have not been studied, we suspect satin bowerbirds are playing an important role in their dispersal. There is incomplete data on the movement patterns and passage rates of seeds among satin bowerbirds, so we can only speculate about the possible distance they may be dispersing seeds. One study showed that immature males can have home ranges of up to 28.67 ha (Maxwell et al. 2004). We suspect the 48 species recorded (Table 1) are only a fraction of the diversity that is ingested and dispersed. We hope this study will generate interest for more detailed and systematic studies throughout the range of the satin bowerbird in eastern Australia.

Acknowledgements

The School of Environmental and Rural Science at the University of New England provided facilities and an International Postgraduate Research Scholarship to the second author. Kelsey Myers Elliott provided editorial insights on the manuscript. We appreciate the insightful review of this manuscript provided by Dr. Karen Sommerville.

References

Borgia G. (1986) Sexual selection in bowerbirds. *Scientific American*, 254, 92-101.

Borgia G. (1995) Why do bowerbirds build bowers? *American Scientist*, 83, 542-547.

Borgia G. & Keagy J. (2006) An inverse relationship between decoration and food colour preferences in satin bowerbirds does not support the sensory drive hypothesis. *Animal Behaviour*, 72, 1125-1133.

Broschat T.K. & Donselman H. (1987) Effects of fruit maturity, storage, presoaking, and seed cleaning on germination in three species of palms. *Journal of Environmental Horticulture*, 5, 6-9.

Campbell M.L., Clarke P.J. & Keith D.A. (2012) Seed traits and seed bank longevity of wet sclerophyll forest shrubs. *Australian Journal of Botany*, 60, 96-103.

Chaffer N. (1945) The spotted and satin bower-birds: a comparison. *Emu*, 44, 161-181.

Chisholm A.H. (1924) Is there any reasonable limit to the ability or the intelligence of Australia's bower-birds? *Emu*, 24, 150.

Cole C.F. (1910) Notes on the Satin Bower-Bird (*Ptilonorhynchus violaceus*). *Emu*, 9, 236-238.

Darwin C. (1888) *The Descent of Man: and selection in relation to sex*. John Murray, Albemarle Street.

Diamond J. (1986) Biology of birds of paradise and bowerbirds. *Annual Review of Ecology and Systematics*, 17, 17-37.

Eddie C. (2001). Spotted bowerbird *Chlamydera maculata* observed eating flower heads of *Acacia salicina. Sunbird: Journal of the Queensland Ornithological Society,* 31, 23-24.

Elliott T.F., Jusino M.A., Trappe J.M., Lepp H., Ballard G., Bruhl J.J. & Vernes K. (2019) A global review of the ecological significance of symbiotic associations between birds and fungi. *Fungal Diversity*, 98, 161-194.

Elliott T.F. & Marshall P.A. (2016) Animal-Fungal Interactions 1: Notes on Bowerbird's Use of Fungi. *Australian Zoologist*, 38, 59-61.

Emery N.J. & Offord C.A. (2019) Environmental factors influencing fruit production and seed biology of the critically endangered *Persoonia pauciflora* (Proteaceae). *Folia Geobotanica*, 54, 99-113.

Emery N.J. & Offord C.A. (2018) Managing *Persoonia* (Proteaceae) species in the landscape through a better understanding of their seed biology and ecology. *Cunninghamia*, 18, 89-107.

Floyd A.G. (2008) *Rainforest trees of mainland south-eastern Australia*. Terania Rainforest Publishing. Lismore, NSW.

Frith C.B. & Frith D.W. (2016) Notes on the nesting biology of the Spotted Bowerbird *Chlamydera maculata* (Ptilonorhynchidae). *Australian Field Ornithology*, 13, 218-225.

Frith C.B. & Frith D.W. (2004) *The Bowerbirds: Ptilonorhynchidae*. Oxford University Press, Oxford.

Frith C.B. (1995) Cicadas (Insecta: Cicadidae) as prey of Regent Bowerbirds *Sericulus chrysocephalus* and other bowerbird species (Ptilonorhynchidae). *Sunbird: Journal of the Queensland Ornithological Society*, 25, 44-48.

Gilliard E.T. (1969) Birds of paradise and bower birds. Natural History, New York.

Green R.J. (1993) Avian seed dispersal in and near subtropical rainforests. *Wildlife Research*, 20, 535-557.

Hansell M. (2007) *Built by Animals: The Natural History of Animal Architecture*. Oxford University Press Inc., New York, NY.

Madden J.R., Dingle C., Isden J., Sparfeld J., Goldizen A.W. & Endler J.A. (2012) Male spotted bowerbirds propagate fruit for use in their sexual display. *Current biology*, 22, R264-R265.

Marshall A.J. (1932) Notes on the Satin Bower-bird. *Emu*, 32, 33-38.

Maxwell P.S., Robson T.E. & Goldizen A.W. (2004) Home range sizes and bower visitation patterns of immature male Satin Bowerbirds (*Ptilonorhynchus violaceus*). *Emu*, 104, 75-77.

Mirov N.T. & Kraebel C.J. (1939) *Collecting and handling seeds of wild plants* (Vol. 49). US Government Printing Office.

Moore G.J. (1991) Seed dispersal by male tooth-billed bowerbirds, *Scenopoeetes dentirostris* (Ptilonorhynchidae), in north-east Queensland rainforests: processes and consequences (Doctoral dissertation, James Cook University of North Queensland).

Pratt T.K. & Stiles E.W. (1983) How long fruit-eating birds stay in the plants where they feed: implications for seed dispersal. *The American Naturalist*, 122, 797-805.

Pruett-Jones M.A. & Pruett-Jones S.G. (1982) Spacing and distribution of bowers in Macgregor's bowerbird (*Amblyornis macgregoriae*). *Behavioral Ecology and Sociobiology*, 11, 25-32.

Williams J.B., Harden G.J. & McDonald W.J.F. (1984) Trees and Shrubs in Rainforests of

New South Wales and southern Queensland. (Department of Botany, University of New England: Armidale.)

Manuscript accepted 17 April 2020

Date of Publication:
May 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Phenology of the threatened *Diuris praecox* (Orchidaceae), a range-restricted terrestrial orchid from central eastern New South Wales

Bonni Yare[1], Stephen Bell[1,3] and Nigel Hunter[2]

[1] School of Environmental and Life Sciences, University of Newcastle,
University Drive, Callaghan, NSW 2308, AUSTRALIA.
[2] NSW National Parks and Wildlife Service, Department of Planning, Industry and Environment,
PO Box 488G, Newcastle, NSW 2300, AUSTRALIA.
[3] Corresponding author stephen.bell@newcastle.edu.au

Abstract: Phenological studies are important to gain insights into the ecology of plant species, particularly those that are threatened and require specific management actions such as regular population monitoring. For many species of terrestrial orchids, limited fundamental knowledge on peak flowering, pollination and seed production restricts effective monitoring outcomes. In this single-season study, phenology data from one population of the vulnerable *Diuris praecox* were collected, with the aim of informing future management relating to monitoring surveys and to assist in conservation of this species.

To this end, six sub-populations (three each in forest habitat and along maintained powerline easements) were visited weekly from the onset of flowering until seed release, with observations made on 134 tagged individuals within 10 x 10 m plots. During the 2019 flowering season, 37% of all plants developed capsules, and 35% released seed. However, success varied between locations, with greater floral displays along powerline easements resulting in stronger pollination rates, while sparse sub-populations in forested locations showed lower pollination. Significantly more flowers per inflorescence (range 1-7) were evident in forest than easement sites, but there was no significant difference in inflorescence height across these habitats. For most sub-populations at least one orchid set seed, even when occurring in low densities (<10 plants). Overall, substantial floral displays did not necessarily result in abundant fruiting, and impacts from desiccation, predation and grazing likely prevented more successful capsule production in any given sub-population.

The synchronously flowering shrubs *Daviesia ulicifolia* and *Pultenaea villosa* co-occurred across all sub-populations, suggesting that the nectar-less *Diuris praecox* may mimic these species to attract pollinators.

Peak flowering was determined to be approximately 20 days from the onset of flowering, with 83% of all plants in flower at that time. For ongoing monitoring, the timing of surveys to occur approximately three weeks after the first observed flowering, will likely maximize return-for-effort, particularly when survey resources are limited, although it is acknowledged that different seasons and populations may vary from this timeframe.

***Cunninghamia* (2020) 20: 105–113**
doi:10.7751/cunninghamia.2020.20.004

© 2020 Royal Botanic Gardens and Domain Trust

Introduction

The Orchidaceae family is one of the most diverse groups of all flowering plants (Fay 2018). This diversity allows orchids to grow in a wide variety of environments, and in some cases their specificity to particular habitats makes them excellent indicators of ecosystem health (Newman *et al.* 2007; Swarts & Dixon 2009). Within the Orchidaceae there is a high proportion of threatened species, a situation evident in Australia (Backhouse 2007) and replicated globally (Swarts & Dixon 2009; Fay 2018). Estimates suggest that in Australia one third of all orchids are terrestrial, the balance being epiphytic or lithophytic on a range of plant and rock hosts (Weston *et al.* 2005; Swarts & Dixon 2009), and threatening processes are widely acknowledged as being greater in terrestrial than in other orchid groups (Duncan *et al.* 2005; Backhouse 2007; Swarts & Dixon 2009). The majority of threats imposed on terrestrial orchids are human-based, and include land clearing, fragmentation, weed and pest introductions, tourism and recreation, and illegal plant collecting (Weston *et al.* 2005; Swarts & Dixon 2009; Wraith & Pickering 2017). However, natural rarity and restricted geographical distributions in some species often mean that impacts from threats are exacerbated. Orchids with reproductive strategies offering a nectariferous reward to visiting pollinators are generally more successful in setting fruit, and consequently more widespread, than are nectar-less species (Neiland & Wilcock 1998).

Terrestrial orchids possess two main life-traits that contribute to their intrinsic rarity; their mycorrhizal association with specific fungal endophytes, and their often specific pollinator requirements, involving pollinator attraction by visual deception or scent (promises of food or sex) to enact pollination (Adams & Lawson 1993; Weston *et al.* 2005; Swarts & Dixon 2009; McCormick & Jacquemyn 2014). As a group, all orchids are primarily pollination limited, the severity of which is tempered by the availability of resources (Tremblay *et al.* 2005) which may vary temporally and geographically. Terrestrial orchids depend on specific fungal associations for the germination of seed and the exploitation or reciprocation of nutrients; the distribution of these fungi across the landscape are influential in where orchid populations flourish (Batty *et al.* 2002; Swarts & Dixon 2009). Mycorrhizal fungi are generally widespread in the landscape, and occur independently of orchid distribution: orchids need fungi, but the reverse is not also true (McCormick & Jacquemyn 2014). High taxonomic diversity in this family is consequently attributed to specialization of either pollinator or mycorrhizal fungi, inherently increasing the risk of extinction in highly specialized species (Tremblay *et al.* 2005; Brundrett 2016; Fay 2018).

Most terrestrial orchids are cryptic geophytes, remaining dormant in the soil for at least six months of the year in the form of an underground tuber, and may remain in that state for up to three years, if environmental conditions are unfavourable (Weston *et al.* 2005). This presents challenges for surveying and monitoring threatened orchids, as many populations flower irregularly while they await suitable environmental conditions (e.g. adequate rainfall at the right time of year); some authors refer to orchids displaying this habit as 'time travelers' (e.g. Brundrett 2016). Further, the variability in magnitude of orchid emergence extends across both time and space (Gillman & Dodd 1998; Kindlmann & Balounová 2001), with populations observed at some locations budding or flowering freely while nearby others in seemingly identical habitat are yet to appear. A wide suite of biological and ecological factors may govern this, including the successful production of seed and its dispersal, the availability of mycorrhizal fungi within the soil, the provision of adequate and timely populations of appropriate pollinators, and suitable environmental conditions to encourage and maintain emergence and flowering (Swarts & Dixon 2009; McCormick & Jacquemyn 2014). Such a range of influential factors ensures that surveys designed to detect terrestrial orchids are often hit-and-miss affairs, beholden to the interaction of climatic and ecological variables which are difficult to control and predict.

Diuris praecox (Rough Double-tail) is a terrestrial nectar-less orchid endemic to a restricted area of central eastern New South Wales (NSW). It is listed as Vulnerable under both the NSW *Biodiversity Conservation Act 2016* (BC Act 2016) and the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. *Diuris praecox* is a site-managed species under the *Saving our Species* (SoS) program being implemented by the NSW Department of Planning, Industry and Environment. Under this initiative, management actions are required to secure this species in the wild for the next 100 years and maintain or improve its conservation status under the BC Act 2016 (OEH 2019). As with many orchid species included in this management stream, annual surveys of known populations are undertaken to monitor their persistence and magnitude, and to identify appropriate actions that may be required to lessen the impact of threats (Emergent Ecology 2018). Previous monitoring actions within this strategy have included the surveying of parallel transects during the flowering season in known and suspected habitat to identify occupancy area, the establishment of permanent monitoring 'macro-plots' to further refine occupancy area, and installation of smaller 10 x 10 m plots within macro-plots to map individuals and investigate reproductive success (Emergent Ecology 2017, 2018; OEH 2019). To date, surveys for this species have occurred at or near perceived peak flowering periods, but there have been no longitudinal survey data across a single season to determine the optimal time to detect this species during surveys.

Given the often unpredictability of flowering in terrestrial orchids, the frequency of visitation and timing of surveys will inevitably affect the outcomes of actions requiring the reporting of population size. Currently there is little knowledge on the best time to conduct surveys for *Diuris praecox*. This paper examines the phenology of one population of *Diuris praecox* over a single season, to identify peak flowering at this location, and investigates the influence of habitat type on flowering and fruiting success.

Study species and population

Diuris praecox occurs in sclerophyll forests with a grassy or dense understorey, on sandy to sandy-clay soils in coastal and near coastal areas of central eastern NSW, from Ourimbah to Nelson Bay (Jones 1991; Emergent Ecology 2017; PlantNET 2019). Larger populations occur in disturbed habitats, along tracks and maintained power line easements, with fewer individuals in adjacent forest habitat. Individuals can occur as isolated plants or in clumps (Jones 2006), and Emergent Ecology (2017) have noted its absence when leaf litter reaches 10 cm depth or greater. There are currently four SoS management sites for this species across its distributional range. The present study was undertaken in one of these, Glenrock State Conservation Area (SCA), which comprises 550 hectares of coastal forest and heath immediately south of Newcastle, between the suburbs of Merewether and Dudley (Figure 1). Urban development surrounds the reserve on three sides, the fourth being the Pacific Ocean. Glenrock SCA is managed by the NSW National Parks and Wildlife Service, and its flora and vegetation have been previously documented in Bell (1998). *Diuris praecox* has been known from Glenrock SCA for several decades, along with other threatened plants including *Cynanchum elegans, Tetratheca juncea* and *Syzygium paniculatum*. Other conserved *Diuris praecox* populations are in Wyrrabalong National Park, Munmorah State Conservation Area, Tomaree National Park and the Worimi Conservation Lands (Bell 1997, 2002; Burton 2008; Bell & Driscoll 2010). No other species of *Diuris* were recorded flowering within our study population at the time of this study.

Like most terrestrial orchids, *Diuris praecox* remains dormant for most of the year, leaves emerging in May and flowering occurring from late July to early September (Jones 2006). Leaves are linear, 150-350 mm long and up to 5 mm wide, and individuals are often associated with habitats supporting a grassy understory, ensuring difficulty in detection prior to flowering. Flowers resemble members of the Fabaceae family ('peas') in shape and colour, and some studies have shown that certain *Diuris* taxa rely on co-occurring pea flowers to attract pollinators to the area through false nectar pathways (Beardsell *et al*. 1986; Indsto *et al*. 2006, 2007). For example, *Diuris maculata* was found to have similar ultra-violet nectar guides to those in the Fabaceae, including red and yellow pea flowers of the genera *Pultenaea* and *Daviesia* (Indsto *et al*. 2006).

Relative to the past three years, Glenrock SCA received below average rainfall in 2019 for all months except June, August and September (BOM 2019). Falls in June at the Burwood Beach weather station (station #061391, located within Glenrock SCA) occurred largely over two six day periods, within the first week and last ten days of the month, and were 106 mm above the average. July rainfall was less than half of the average, but spread over two periods early and late in the month. In August (28 mm above average), 89 mm of rain fell over the last two days, while in September (40 mm above average) 101 mm fell in the first two days of the month. For the late winter flowering *Diuris praecox*, these falls were sufficient to saturate the soil prior to flowering, and then to maintain soil moisture over the full flowering period.

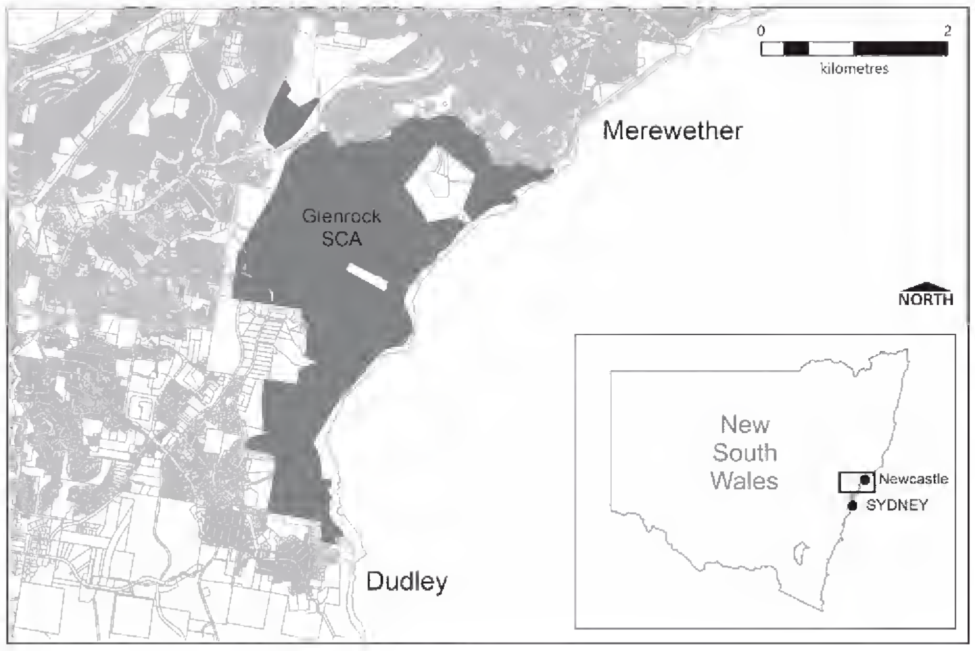


Figure 1: Location of Glenrock State Conservation Area (SCA) within central eastern New South Wales.

Methods

Six sub-populations of *Diuris praecox* in Glenrock SCA form the basis of this study (Figure 2); three along regularly slashed powerline easements ('easement': sub-populations A to C), and three in undisturbed forest habitat ('forest': sub-populations D to F). Monitoring plots 10 x 10 m in size were established in each sub-population, and a 1-metre grid was used to progressively map and tag all individuals with a unique number. Tags were placed in the ground c. 10 cm from the flower stem to avoid damaging tubers. In cases where several stems occurred in close proximity, only a single individual was tagged; a minimum separation distance of 30 cm was used to demarcate the next nearest tagged plant.

This study focused on monitoring orchids at weekly intervals (from August to September 2019). For each tagged plant, information on flowering status and micro-habitat was recorded, including: inflorescence stem height (in cm); presence and number of buds; flowering number and stage (closed, fully open, wilting); evidence of pollination (ovary swelling, capsule development); capsule number and stage (dehisced with seed release, fail); apparent abortion or cessation of flowering (not pollinated, trampled, predated, other/unknown); and micro-habitat (grass, leaf litter, moss etc.). As *Diuris* inflorescences open acropetally, flowering stage of the least advanced flowers on each inflorescence only were recorded, and represented flowering progress of that individual at each inspection. For example, an individual was categorized as in flower only when no developing buds were present, but was scored as in bud if all but one flower was yet to open. Additional habitat information, such as associated plant species occurring within each plot, vegetation height (within easements only), observable threatening processes and/or disturbance events, was also recorded. Co-occurring peas observed to be flowering synchronously with *Diuris* were also noted.

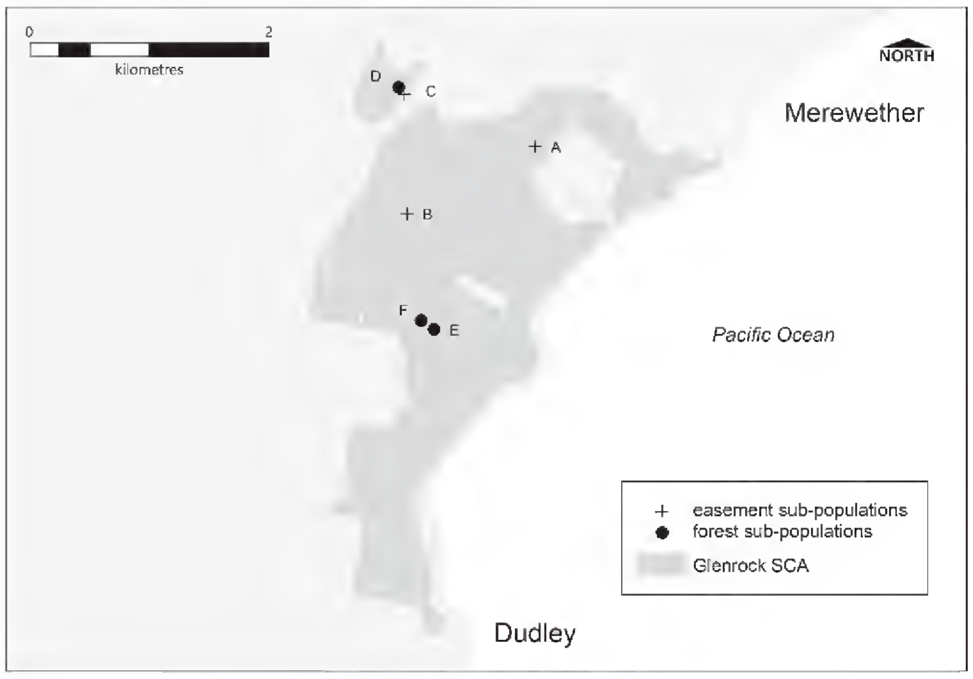


Figure 2: Study sub-populations within Glenrock State Conservation Area.

Data were analysed with JMP software (SAS Institute 2019) to investigate differences in flowering and capsule development, peak flowering and inflorescence stem height between the two habitat types (forest, easement). Independent-samples t-tests were used to test for significance in the number of flowers per inflorescence and inflorescence height across easement and forest sites. Analysis of variance and bivariate linear regression were used to determine whether there was a relationship between flower display and fruit set. A graph of flower numbers against visitation was constructed to determine peak flowering.

Results

Diuris praecox detection

The maximum number of individuals was quickly reached in all plots (Figure 3) particularly for subpopulations in easements (sub-populations A to C), where 28-55% of individuals were detected after the initial visit. For sub-population E (forest), no additional *Diuris* were located after the first detection at Visit 2, and unexplained removal of tags at Visit 6 curtailed further monitoring of this sub-population. Most plants had been detected within each sub-population by Visit 3. A total of 134 *Diuris* were located across all sub-populations; 24.6% of these were detected while still in bud, 74.6% were in flower, and 0.8% when flowers were wilting (Table 1).

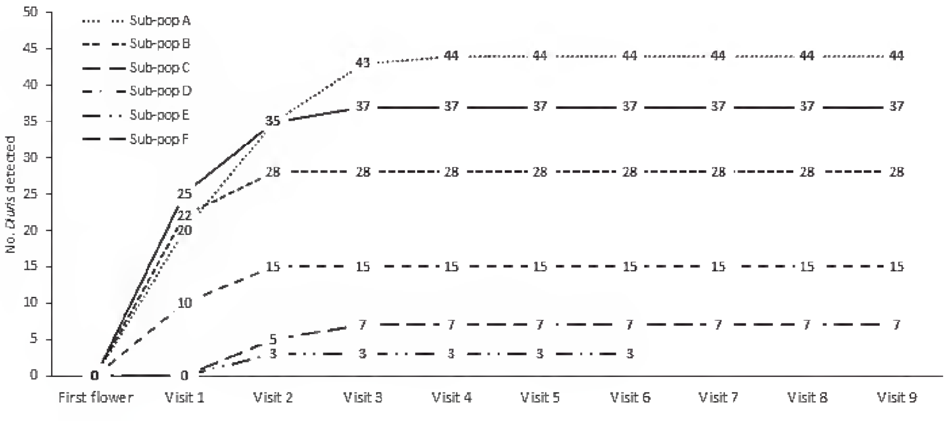


Figure 3: Cumulative total of *Diuris* detected at each sub-population. Sub-populations A to C = Easement, D to F = Forest.

Table 1: Flowering stage of *Diuris praecox* at first detection, Glenrock SCA.

		Flowering stage			
Habitat	Sub-population	Buds	Open flowers	Wilted flowers	Total plants
Easement	A	14	30	-	44
	B	6	22	-	28
	C	8	28	1	37
Forest	D	3	12	-	15
	E	-	3	-	3
	F	2	5	-	7
	Total	33	100	1	134
	Proportion (%)	25	75	<1	100

Flowering Period

First flowering in *Diuris* was detected on the 29th of July 2019. Weekly inspections subsequently commenced on 7 August and continued until no further flowering was observed within plots, on 17 September 2019. The total flowering period spanned 42 days, and incorporated six visits to all plots over this period (Visit 1, 7-12 August; Visit 2, 17-19 August; Visit 3, 24 August; Visit 4, 2 September; Visit 5, 8 September; Visit 6, 17 September). Three additional visits subsequent to this to monitor capsule development did not record any further flowering.

Flowering was at its peak on Visit 2, with most flowering occurring during the initial three weeks of observations (Figure 4). Expressed as a proportion of the total tagged population (n = 134), flowering peaked at Visit 2 (73.1%), while fruiting peaked at Visit 5 (74.6%). Most flowers had either been grazed, failed to be fertilized or were developing capsules by Visit 4, however the occasional flower was observed up until Visit 5. Some buds did not progress to flowering or fruiting, and a small number of new individuals evaded detection when in flower and were discovered only when in fruit. No flowering was recorded on Visit 6 or subsequently. Buds were last observed at Visit 3, with flowering finishing up by the following inspection one week later. Pollination was first detected on Visit 2, and the first capsules were observed on Visit 4. Seed set was first recorded at the beginning of October and continued into mid-October and beyond.

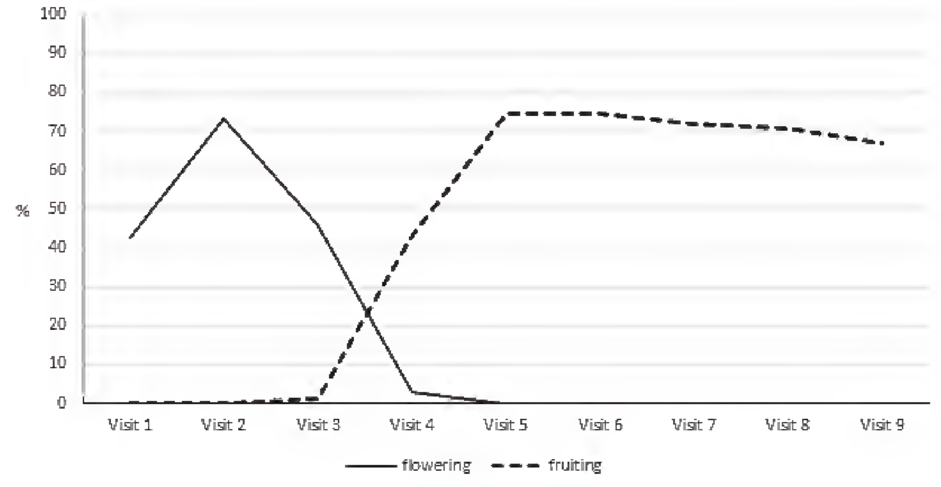


Figure 4: Percentage of *Diuris* flowering (n = 100) and fruiting (n = 59) across all sub-populations at Glenrock SCA over the full monitoring period.

No. of flowers per stem

For individually tagged orchids (n = 95), the minimum number of flowers per inflorescence was one, the maximum was seven, and the overall mean was 3.34 +/- 1.47 (Figure 5). An independent-samples t-test showed there to be a significant difference between the number of flowers in easement ($\bar{x}$ = 3.19, SD = 1.40) and forest ($\bar{x}$ = 3.94, SD = 1.61) sites: t(93) = 1.990, p = 0.0495. This suggests that more flowers are borne on inflorescences occurring in forest than in easements, and perhaps reflects the observation that plants in forest habitat tend to be taller than those that have colonized easements.

Successful capsule development

First development of capsules was observed on Visit 3 at sub-population A (easement) on 24 August, and most capsules were evident across the majority of sub-populations on Visit 5 and Visit 6 (Figure 4). No capsules were observed at sub-population E (forest), and only one at sub-population F (forest). Of 53 capsules developing, all but one (in sub-population A) progressed to seed release. Sub-population B (easement) had the highest level of capsule development, with 82% of individuals progressing to seed (Figure 6). This is significantly higher than other sub-populations examined and comprises approximately half of all other orchids successfully reaching this stage. Sub-populations E and F (both forest) returned particularly low rates of capsule development, only one orchid progressing to seed. Cessation of flowering/fruiting due to grazing, as determined by missing flowers/fruit and chewed stems, was significantly higher at sub-population C (46%) than all other areas. This site was seen to be infested with a large number of phasmid insects not present elsewhere, and although no direct observations of grazing were made it is posited that these insects grazed on flowers and/or capsules.

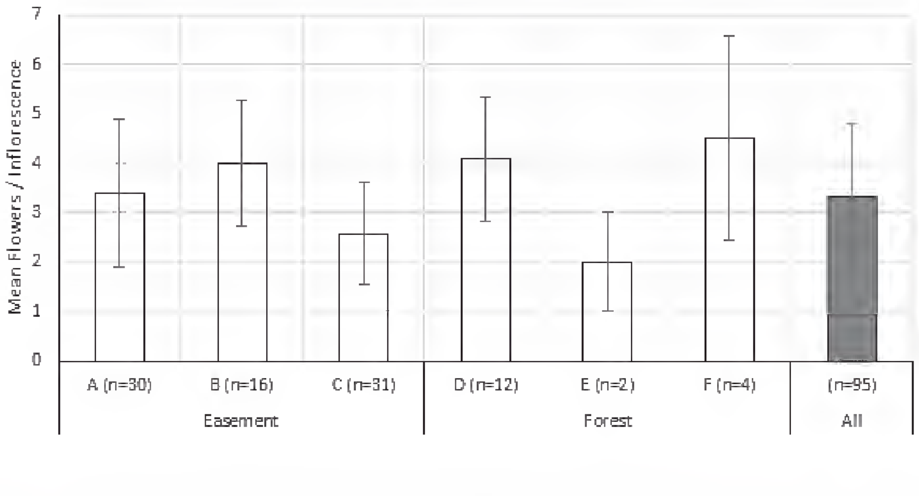


Figure 5: Mean (with standard deviations) of the number of *Diuris* flowers per inflorescence across all sub-populations in easement (A-C) and forest (D-F) sites at Glenrock SCA.

Overall, flower display and fruit development gave a strong positive relationship across all sub-populations, with a correlation of r = 0.77. However, regression analysis (Figure 7) returned an R^2 value of 0.59, indicating only a moderate fit for all samples and this was not significant (p = 0.075). This suggests that substantial floral display in this species does not necessarily result in abundant fruit production, likely due to factors such as desiccation and grazing.

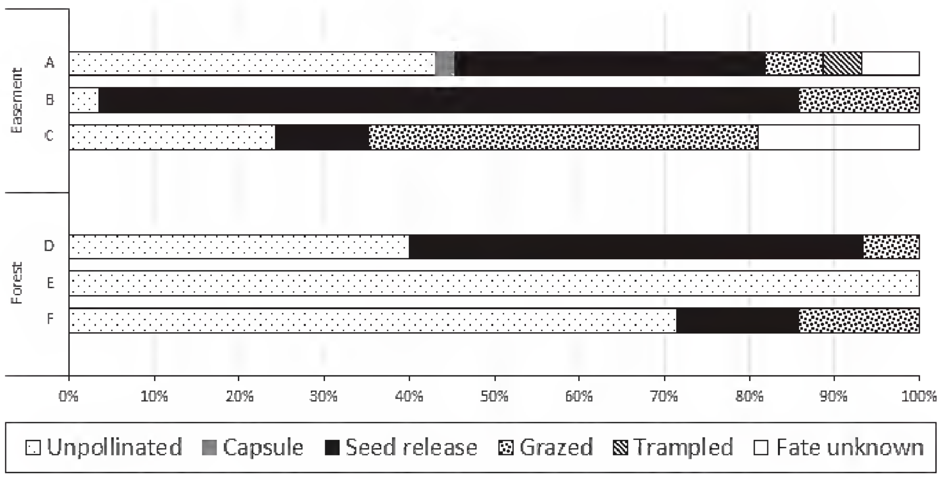


Figure 6: Fate of 134 *Diuris praecox* individuals within Easement (sub-populations A to C) or Forest (sub-populations D to F) habitats, showing relative proportion remaining un-pollinated and those attaining or failing to reach capsule or seed release stage.

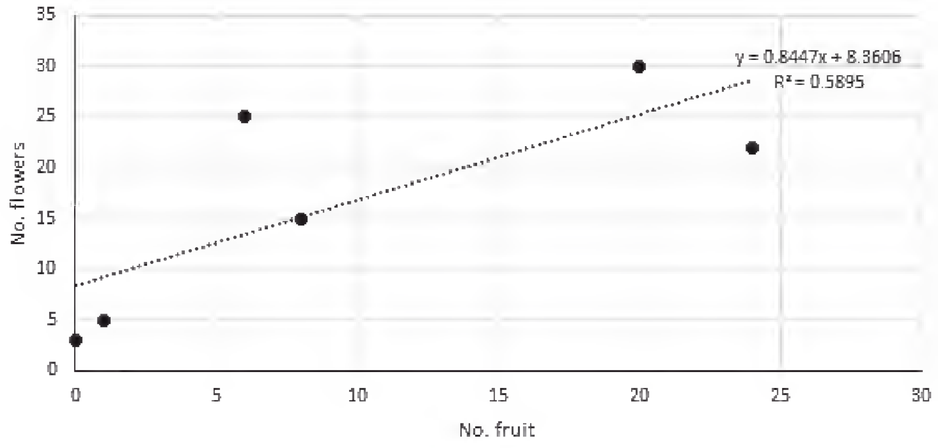


Figure 7: Regression analysis of flower display and fruit development in *Diuris praecox* across six study sub-populations.

Growth habit & associated species

Across all plots, 25% of tagged individuals occurred in a clumped arrangement (several stems <30 cm apart) rather than as widely spaced individuals. These clumps may possibly be clonal, although a more likely explanation is leptokurtic dispersal (seed dispersal close to founding individuals). Overall mean stem height of flower inflorescences was 22.8 cm (n = 107) for easement and 24.4 cm (n = 25) for forest sub-populations. Although sample sizes were unequal, a Levene test returned a non-significant result (f = 1.718, p = 0.192), suggesting that variances were homogeneous. An independent-samples t-test subsequently showed there to be no significant difference in inflorescence height between easement ($\bar{x}$ = 2.80, SD = 7.13) and forest ($\bar{x}$ = 24.42, SD = 6.00) sites: t(133) = 1.050, p = 0.2955.

At the micro-habitat scale, most *Diuris* were found growing amongst grass, most commonly *Themeda triandra* (20%) or other grass species (39%), while some sub-populations were in bare ground (10%), or within clumps of *Lomandra longifolia* (7%) or in leaf litter (7%). Some *Diuris* occurred under shrubs (10%), but this was a rarity. Collectively, *Diuris* occurred within habitat dominated by a canopy of *Angophora costata, Eucalyptus acmenoides, E. paniculata, E. punctata* and *Corymbia maculata*, although such species were absent along easement sites. Native shrubs present in this habitat comprised *Acacia ulicifolia, A. irrorata, A. stricta, A. longifolia, A. falcata, Breynia oblongifolia, Daviesia ulicifolia, Dodonaea triquetra, Leucopogon juniperinus,* *Pittosporum undulatum* and/or *Pultenaea villosa*. Common ground layer species included the grasses *Entolasia stricta, Imperata cylindrica* and *Themeda triandra*, the graminoids *Lomandra longifolia, L. multiflora* and *Dianella caerulea*, the fern *Cheilanthes sieberi*, and the forb *Lobelia purpurascens*. Weed species, such as *Andropogon virginicus, Asparagus aethiopicus, Briza subaristata, Lantana camara* and *Lilium formosanum* were also present to varying degrees in some sub-populations.

Within the immediate vicinity of study plots, the shrubs *Daviesia ulicifolia* and *Pultenaea villosa* (both Fabaceae) flowered synchronously with *Diuris praecox* and were present at all sub-populations. *Pultenaea villosa* came into flower during Visit 2 (mid-August), and flowering in this species appeared to be heaviest from mid-August to the beginning of September. *Daviesia ulicifolia* flowered earlier than *Pultenaea villosa*, and remained in bloom for the duration of the survey period. The abundance of both of these species appeared to be typically greater at the easement locations, although this attribute was not measured quantitatively. Other species also in flower at this time were *Hibbertia dentata* (Dilleniaceae) and *Hardenbergia violacea* (Fabaceae). No observations on visitation by potential pollinators to either *Diuris praecox* or these co-occurring species were made at the time of surveys.

Discussion

Diuris detection and flowering trends

As with most terrestrial orchids, *Diuris* is visible predominantly when in flower and hence there is clearly a greater chance that individuals will be detected in plant surveys during this life-stage. This is particularly so for those species with bright and showy flowers, like most *Diuris*, that are easily detected by the human eye. However, it should never be assumed that all individuals of an orchid population will be detected in targeted surveys (Sanger & Waite 1998; Kéry & Gregg 2003; Bell 2019). There is a range of factors influencing detectability on any given day, such as available soil moisture, ambient temperatures, pressures from grazing and trampling on flowering stems, asynchronous flower opening of individuals and populations, experience of field surveyors, and over-shading or shielding by co-occurring vegetation (Duncan *et al*. 2005; Backhouse 2007; Light & MacConaill 2007; Milberg *et al*. 2008; Swarts & Dixon 2009; Duncan & Moloney 2018). One way to reduce uncertainty of knowing when to best survey a population is to identify the peak flowering period. An identified peak may not necessarily be consistent from year to year (Kindlmann & Balounová 2001), but it will give some guidance when planning monitoring surveys. Importantly, the implicit assumption made by many field workers that all plants in a search area will always be found may often prove incorrect (Kéry & Gregg 2003; Milberg *et al*. 2008).

For the study population of *Diuris praecox* at Glenrock SCA, peak flowering occurred on Visit 2, twenty days after the first open flower was observed. At this time, a large proportion (83%) of all plants were flowering, and by Visit 4 (c. 35 days post first-flower) the bulk of orchids had ceased flowering. Limited rainfall at this time may have shortened the overall flowering period, although this is not expected to have been a significant constraint. It required four visits to sub-population A (easement, 44 *Diuris*) to detect all individuals, which was considerably longer than all other sub-populations, and this trend has been noted previously (pers. obs.; Emergent Ecology 2018). This may have been due to the difficulty in detecting orchids amongst the dense grass/shrub ground layer at this location, or may suggest that this sub-population has a longer flowering span. Initial detection and tagging of some *Diuris* individuals was enacted while in bud (25%), but the majority were in full flower. One individual was not located until flowering had ceased, implying that others may also have been overlooked in the dense ground layer vegetation.

Pollination & pea flower presence

Diuris is one of several terrestrial orchid genera that commonly rely on visual deception (mimicry) to attract pollinators to their predominantly nectar-less flowers (Adams & Lawson 1993; Brundrett 2019). In these situations, successful pollination will only occur if nectar-producing, synchronously flowering non-orchid plants displaying similar floral features occur within and around *Diuris* populations. With few exceptions in this genus, pollinators are mistakenly attracted to *Diuris* flowers in the belief that a reward of nectar awaits them. Some previous studies have drawn a link between successful fruit development in *Diuris* with co-occurring pea species from the Fabaceae family. Beardsell *et al*. (1986), for example, documented how *Diuris maculata* fruiting success was tied to the presence of *Daviesia virgata, D. mimosoides* and *Pultenaea scabra*, all three of which flowered synchronously with *Diuris* during their study. Vizer (2013) suggested that the shrubs *Templetonia stenophylla* and *Daviesia genistifolia* may be important species to attract pollinators to areas where the vulnerable *Diuris tricolor* occurs in the upper Hunter Valley, and Indsto *et al*. (2007) targeted *Daviesia ulicifolia* in an effort to capture potential pollinators in their study of *Diuris maculata*.

Although not assessed quantitatively, a greater proportion of synchronously flowering pea plants (*Daviesia ulicifolia, Pultenaea villosa*) were observed within easements compared to forests at Glenrock SCA, suggesting that high pollination rates at these sub-populations may have been assisted by pea co-occurrence. This trend was variable, however, with sub-population B (showing the highest rate of pollination success at 82% from 28 *Diuris*) occurring in an easement dominated by exotic grasses with minimal shrubs. No flowering peas were present within the study plot here, although they were evident 5-10 m away in the adjacent forest and were dominant in the easement approximately 20-50 m from the plot. In contrast, sub-population A (also an easement, with 44 *Diuris*) supported many individuals of *Daviesia ulicifolia* and *Pultenaea villosa* but returned a success rate of only 39%. Sub-population C (easement, 37 *Diuris*) similarly had a high presence of *Daviesia* and *Pultenaea* but a low pollination success rate (11%). The most likely cause for this poor result is presumed grazing by a species of phasmid (stick insect, c. 8 cm long), which were observed in large numbers within the study plot on Visit 4. To our knowledge, there is no mention elsewhere in the literature of phasmids grazing on *Diuris* or other terrestrial orchids, although a range of other insects (including beetles, weevils, flys, bugs, wasps, butterflies, moths, thrips) have been observed and implicated elsewhere (Light & MacConaill 2011). Phasmids have been briefly noted as feeding on epiphytic orchids (including *Dendrobium*, possibly in cultivation) in Singapore (Ridley 1894), but this remains the only reported evidence of such herbivory.

At the Glenrock population, *Hibbertia dentata* (Dilleniaceae) and *Hardenbergia violacea* (Fabaceae) were also flowering synchronously with *Diuris praecox*, although to a considerably lesser extent. These two species may also play a role in attracting pollinators, given the suggestion by Brundrett (2019) that other representatives in these genera attract pollinators to *Diuris magnifica* colonies in Western Australia. A review of all Fabaceae recorded for Glenrock SCA in Bell (1998) suggests several other possible mimic models (e.g. *Phyllota phylicoides, Podolobium ilicifolium, Pultenaea daphnoides, P. euchila, P. paleacea* and *P. retusa*), however few of these were observed in the vicinity of the *Diuris* study sub-populations.

Irrespective of synchronously flowering peas, successful pollination and capsule development within the study population of *Diuris praecox* was generally higher in areas where greater densities of the orchid were evident, such as in easement sites. Sub-population D (forest, 15 *Diuris*) at Glenrock also showed a high pollination/capsule development rate, which supported more *Diuris* than all other forest sub-populations (range 3 to 10). Good rainfall received in August and early September, corresponding with the fruiting phase, likely contributed to successful capsule development across this and all studied sub-populations. Overall, regression analysis showed that substantial floral displays do not necessarily result in abundant fruiting, and impacts from grazing likely prevent more successful capsule production in any *Diuris* population. As in this study, other research with *Diuris* has shown greater presence and flowering in open habitats rather than in forest (e.g. Burton 2008; Vizer 2013; Tierney *et al*. 2017), although proximity to habitats where sufficient nectar-producing species occur will always be important for long-term persistence.

Growth habit

One in four plants of *Diuris praecox* occurred within a clump (<30 cm from neighbours), however the bulk of detected orchids presented as individuals. As no further investigation was undertaken within clumps, it is unknown if these plants are clonal or represent several individuals from a previous successful germination event. Orchids emerging in close proximity to one another may be distinct individuals, having germinated in an area where the necessary mycorrhizal fungi were particularly abundant, however most cases of aggregated distributions in orchids are thought to be a result of clonal growth (Bates 1986; Brundrett *et al*. 2003). Vizer (2013) considered laboratory-raised specimens of *Diuris tricolor* bearing three leaves (rather than the usual 1-2) to be clonal, after finding leaf emergent points on axillary branches of tubers.

Although not significant, inflorescence stem height differed between easement and forest sub-populations, with the former having shorter average stems than the latter. This may be due to a number of factors, and one possibility is that the higher densities of orchids along easements reflect a cohort of younger plants that have colonized these habitats since easement creation. Taller orchids, such as are present in forested habitats, are more likely to be older and have larger storage reserves, enabling greater vegetative growth including a larger number of flowers with taller stems (Gregg & Kéry 2006). They may also be a developmental consequence of the need to grow taller to outcompete surrounding vegetation. Significantly more flowers per inflorescence were found in forest than easement habitat, supporting suggestions that older, taller individuals bear more flowers than younger plants.

Implications for management

The results of this study can now be applied to the management of *Diuris praecox* at Glenrock SCA and at other populations. For this late-winter flowering species, the greatest number of open flowers occurred approximately three weeks (20 days) after the first detection of a flowering individual in the population. This would suggest that monitoring surveys designed to quantify the size of a population, when survey resources are limited, are best undertaken approximately twenty days after first flowering. However, if resourcing allows for more regular surveys repeated inspections of an area either side of this optimum are more likely to capture a greater proportion of individuals in a population.

Although dense colonies of *Diuris praecox* appear to attract sufficient pollinators (such as occurred at easement sub-populations), this study has also implied that successful pollination of sparse colonies and isolated individuals will likely be greatly assisted by the presence of the synchronously flowering *Daviesia ulicifolia* and *Pultenaea villosa*. Management of the habitats supporting *Diuris* should therefore ensure that populations of these peas are maintained in the near vicinity of known orchid sub-populations, preferably in a mosaic pattern of age classes to ensure ongoing supply of reward for pollinating insects. Both of these peas require regular fire to replenish their populations (Benson 1985; Benson & McDougall 1996; Clarke *et al*. 2009), however fires of high frequency may potentially render them locally extinct. Many species of *Daviesia* (but not *D. ulicifolia*; Benson & McDougall 1996) also reportedly resprout following fire, although this will likely depend on fire intensity. Flowering in both *Daviesia* and *Pultenaea* generally does not occur for the first three years after fire (Benson & McDougall 1996), and for *Diuris maculata* Brown *et al*. (2007) suggested that the limited availability of these nectar-rewarding species immediately post-fire may restrict pollination of this species of *Diuris*. Additionally, they raise the possibility that pollinator activity may be influenced by moisture availability (rainfall) in and around *Diuris* and pea populations, ultimately reducing the extent of capsule development. While for *Diuris praecox* this remains untested, the interplay of rainfall and fire at Glenrock SCA may prove important in the maintenance of pollinating insect populations.

Terrestrial orchids are prone to a wide range of threats, both natural and man-made (Duncan *et al*. 2005; Backhouse 2007; Swarts & Dixon 2009; Wraith & Pickering 2017). Grazing by vertebrates and invertebrates is perhaps one of the most pressing natural stressors operating on orchid populations, yet it is relatively poorly understood. This is particularly the case for invertebrate grazing; observations made in this study of the potential predation on *Diuris* by phasmids, and its impact on the production of fruiting capsules, has not been previously reported in the literature (see Light & MacConaill 2011). Further research into how these insects affect population dynamics would be beneficial, and managers may need to monitor and act upon these insects during *Diuris* flowering, perhaps through the use of grazing exclusion cages.

Acknowledgements

Thanks to Max Manon, Callum Reedman, Cameron Morgan and Alaina Casey for field assistance, and Lachlan O'Neil for statistical advice. Peter Weston provided several insightful comments during review, and these significantly improved the manuscript.

References

Adams, P.B. & Lawson, S.D. (1993) Pollination in Australian orchids: A critical assessment of the literature 1882-1992. *Australian Journal of Botany* 41: 553-575.

Backhouse, G.N. (2007) Are our orchids safe down under? A national assessment of threatened orchids in Australia. *Lankesteriana* 7(1-2): 28-43.

Bates, R. (1986) Delightful *Diuris*: the Donkey Orchid. *Australian Orchid Review* 51: 12-18.

Batty A.L., Dixon K.W., Brundrett M.C., & Sivasithamparam K. (2002) Orchid Conservation and Mycorrhizal Associations. In: Sivasithamparama K., Dixon K.W., Barrett R.L. (eds) *Microorganisms in Plant Conservation and Biodiversity*. Springer, Dordrecht.

Beardsell, D., Clements, M., Hutchinson, J. & Williams, E. (1986) Pollination of *Diuris maculata* R Br (Orchidaceae) by floral mimicry of the native legumes *Daviesia* spp and *Pultenaea scabra* R Br. *Australian Journal of Botany* 34(2): 165-173.

Bell, S.A.J. (1997) *Tomaree National Park vegetation survey: a fire management document*. Eastcoast Flora Survey. Report to NSW National Parks and Wildlife Service (Hunter District). May 1997.

Bell, S.A.J. (1998) *Glenrock SRA and Awabakal NR vegetation survey. A fire management document. Volumes 1 & 2*. Eastcoast Flora Survey. Report to NSW National Parks and Wildlife Service (Hunter District). August 1998.

Bell, S.A.J. (2002) *The natural vegetation of the Wyong Local Government Area, Central Coast, New South Wales*. Parts 1 & 2. Report to Wyong Shire Council. Eastcoast Flora Survey.

Bell, S. (2019) Threatened plant translocation case study: Translocation 'success' is all about detection: experiences with two threatened orchids from the Hunter Valley of NSW. *Australasian Plant Conservation* 28(1): 27-31.

Bell, S.A.J. & Driscoll, C. (2010) *Vegetation of the Worimi Conservation Lands, Port Stephens, New South Wales: Worimi NP, Worimi SCA & Worimi RP*. Unpublished Report to NSW Department of Environment, Climate Change & Water. Eastcoast Flora Survey. November 2010.

Benson, D.H. (1985) Maturation periods for fire-sensitive shrub species in Hawkesbury Sandstone vegetation. *Cunninghamia* 1(3): 339-349.

Benson, D. & McDougall, L. (1996) Ecology of Sydney plant species. Part 4: Dicotyledon family Fabaceae. *Cunninghamia* 4(4) 553-752.

Brown, J. & York, A. (2017) Fire, food and sexual deception in the neighbourhood of some Australian orchids. *Austral Ecology* 42: 468–478.

Brundrett, M.C. (2016) Using vital statistics and core-habitat maps to manage critically endangered orchids in the Western Australian wheatbelt. *Australian Journal of Botany* 64: 51–64.

Brundrett, M.C. (2019) A comprehensive study of orchid seed production relative to pollination traits, plant density and climate in an urban reserve in Western Australia. *Diversity* 11(8): 123. https://doi.org/10.3390/d11080123

Brundrett, M.C., Scade, A., Batty, A.L., Dixon, K.W., & Sivasithamparam, K. (2003) Development of in situ and ex situ seed baiting techniques to detect mycorrhizal fungi from terrestrial orchid habitats. *Mycological Research* 107(10): 1210-1220.

Bureau of Meteorology (BOM) (2019) Climate data online. Merewether (Burwood Beach Wwtp). Available at: http://www.bom.gov.au/climate/data/ [Accessed 30 Oct. 2019]

Burton, E. (2008) Terrestrial orchids of the Tomaree Peninsular. *The Orchadian* 15(11): 511-513.

Clarke, P.J., Knox, K.J.E., Campbell, M.L., & Copeland, L.M. (2009) Post-fire recovery of woody plants in the New England Tableland Bioregion. *Cunninghamia* 11(2): 221-240.

Duncan, M. & Moloney, P.D. (2018) Comparing wild and reintroduced populations of the threatened orchid *Diuris fragrantissima* (Orchidaceae) in south-eastern Australia. *Australian Journal of Botany* 66: 459-467.

Duncan, M., Pritchard, A., & Coates, F. (2005) Major threats to endangered orchids of Victoria, Australia. *Selbyana* 26(1-2): 189-195.

Emergent Ecology (2017) *Saving Our Species Targeted Survey for* Diuris praecox. Prepared by Emergent Ecology on behalf of Office of Environment and Heritage, November 2017.

Emergent Ecology (2018) *Saving Our Species Targeted Survey for* Diuris praecox. Prepared by Emergent Ecology on behalf of Office of Environment and Heritage, November 2018.

Fay, M.F. (2018) Orchid conservation: how can we meet the challenges in the twenty-first century? *Botanical Studies* 59: 16

Gillman, M.P. & Dodd, M.E. (1998) The variability of orchid population size. *Botanical Journal of the Linnean Society* 126(1-2): 65–74.

Gregg, K. & Kéry, M. (2006) Comparison of size vs. life-state classification in demographic models for the terrestrial orchid *Cleistes bifaria*. *Biological Conservation* 129(1): 50-58.

Indsto, J., Weston, P., Clements, M., Dyer, A., Batley, M. & Whelan, R. (2006) Pollination of *Diuris maculata* (Orchidaceae) at Scheyville National Park, NSW by male *Trichocolletes venustus* bees. *Australian Journal of Botany* 54: 669–679.

Indsto, J., Weston, P., Clements, M., Dyer, A., Batley, M. & Whelan, R. (2007) Generalised pollination of *Diuris alba* (Orchidaceae) by small bees and wasps. *Australian Journal of Botany* 55(6): 628-634.

Jones, D.L. (1991) New taxa of Australian Orchidaceae. *Australian Orchid Research* 2: 1-208.

Jones, D. (2006) *A complete guide to native orchids of Australia including the island territories*. Frenchs Forest, N.S.W.: New Holland.

Kery, M. & Gregg, K.B. (2003) Effects of life-state on detectability in a demographic study of the terrestrial orchid *Cypripedium reginae*. *Journal of Ecology* 91:265-273.

Kindlmann, P. & Balounová, Z. (2001) Irregular flowering patterns in terrestrial orchids: theories vs empirical data. *Web Ecology* 2: 75-82.

Light, M.H.S. & MacConaill, M. (2007) Effects of trampling on a terrestrial orchid environment. *Lankesteriana* 7(1-2): 294-298.

Light, M.H.S. & MacConaill, M. (2011) Potential impact of insect herbivores on orchid conservation. *European Journal of Environmental Sciences* 1(2): 115-124.

McCormick, M.K. & Jacquemyn, H. (2014) What constrains the distribution of orchid populations? *New Phytologist* 202: 392-400.

Milberg, P., Bergstedt, J., Fridman, J., Odell, G., & Westerberg, L. (2008) Observer bias and random variation in vegetation monitoring data. *Journal of Vegetation Science* 19(5): 633-644.

Neiland, M.R.M. & Wilcock, C.C. (1998) Fruit set, nectar reward and rarity in the Orchidaceae. *American Journal of Botany* 85(12): 1657-1671.

Newman, B.J., Ladd, P., Batty, A., & Dixon, K. (2007) Ecology of orchids in urban bushland reserves – can orchids be used as indicators of vegetation condition? *Lankesteriana* 7(1-2): 313-315.

Office of Environment & Heritage (OEH) (2019) Rough Doubletail (*Diuris praecox*), Conservation project. Available at: https://www.environment.nsw.gov.au/savingourspeciesapp/project.aspx?ProfileID=10240 [Accessed 29 Aug. 2019].

PlantNET (2019) *PlantNET - FloraOnline*. Available at: http://plantnet.rbgsyd.nsw.gov.au/cgi-bin/NSWfl.pl?page=nswfl&lvl=sp&name=Diuris~praecox [Accessed 29 Aug. 2019].

Ridley, R.N. (1894) Stick-insects destroying orchids. *Journal of the Straits Branch of the Royal Asiatic Society* 26: 204.

Sanger, N. & Waite, S. (1998) The phenology of *Ophrys sphegodes* (the early spider orchid): what annual censuses can miss. *Botanical Journal of the Linnean Society* 126(1-2): 75-81.

Swarts, N. & Dixon, K. (2009) Terrestrial orchid conservation in the age of extinction. *Annals of Botany* 104(3): 543-556.

Tierney, D., Sommerville, K., Tierney, K., Fatemi, M. & Gross, C. (2017) Trading populations—can biodiversity offsets effectively compensate for population losses? *Biodiversity and Conservation* 26(9): 2115-2131.

Tremblay, R.L., Ackerman, J.D., Zimmerman, J.K., & Calvo, R.N. (2005) Variation in sexual reproduction in orchids and its evolutionary consequences: a spasmodic journey to diversification. *Biological Journal of the Linnean Society* 84:, 1–54.

Vizer C. (2013) *Contributions to the understanding of the ecology and biology of* Diuris tricolor *and* Prasophyllum *sp. Wybong in the Upper Hunter Region, NSW*. Unpublished BSc (Hons) thesis, University of Newcastle.

Weston, P., Perkins, A., & Entwisle, T. J. (2005) More than symbioses: orchid ecology, with examples from the Sydney Region. *Cunninghamia*. 9: 1-15.

Wraith, J. & Pickering, C. (2017) Tourism and recreation a global threat to orchids. *Biodiversity and Conservation* 26: 3407-3420.

Manuscript accepted 27 April 2020

Date of Publication:
June 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Myxomycetes Of Norfolk Island, South Pacific Ocean

Steven L. Stephenson[1] *and Barbara C. Stephenson*[2]

[1]Department of Biological Sciences, University of Arkansas, Fayetteville, Arkansas 72701 USA.
[2]Department of Mathematics, University of Arkansas, Fayetteville, Arkansas 72701 USA.

***Abstract*:** A survey for myxomycetes (plasmodial slime moulds or myxogastrids) was carried out on Norfolk Island in June 2019. The overall objective was to collect both specimens that had fruited in the field under natural conditions as well as specimens appearing in moist chamber cultures prepared with samples of dead plant material collected on the island. However, only three species were recorded as field collections over a period of almost two weeks, so the primary focus of the survey was redirected to collecting samples for moist chamber cultures. Approxmately 120 samples of dead plant material collected from 21 different sampling sites on the island and used to prepare 356 moist chamber cultures yielded a total of 497 specimens. These specimens included at least 48 species in 18 genera. This brings the total number of species and genera now known from Norfolk Island to 55 and 19, respectively.

***Cunninghamia* (2020) 20: 115-121**
doi: 10.7751/cunninghamia.2020.20.005

© 2020 Royal Botanic Gardens and Domain Trust

Introduction

Myxomycetes (plasmodial slime moulds or myxogastrids) are a group of fungus-like organisms associated with dead plant material in virtually every type of terrestrial ecosystem investigated to date, with approximately 1000 species known worldwide (Lado 2005–2019). The myxomycete life cycle encompasses two very different trophic (feeding) stages, one consisting of uninucleate amoebae, with or without flagella (the term "amoeboflagellate" is used to refer to both types), and the other consisting of a distinctive multinucleate structure, the plasmodium (Martin et al. 1983). Under favorable conditions, the plasmodium gives rise to one or more fruiting bodies containing spores. The fruiting bodies produced by myxomycetes are somewhat suggestive of those produced by higher fungi, although they are considerably smaller (usually no more than 1–2 mm tall).

Norfolk Island is a small island in the South Pacific Ocean located between Australia (1600 km northeast of Sydney) and New Zealand (1100 km northwest of Auckland) (Fig. 1). The island (167° 57' E, 29° 02' S), an Australian external territory, was formed approximately 2.5 million years ago as a result of volcanic activity. Most the island (which has a total extent of only about 35 km^2) consists of an elevated plateau (Fig. 2A), and the highest elevation is 319 m (Mount Bates). The climate is subtropical, and only about 10% of the vegetation is relatively undisturbed. Most of the latter is encompassed in Norfolk Island National Park. Norfolk Island pine (*Araucaria heterophylla* [Salisb.] Franco), now widely planted throughout the tropics and subtropics, is endemic to the island (Fig. 1B).

In April and May 1995, Heino Lepp from the Australian National Herbarium visited Norfolk Island. During his visit, he collected 11 specimens of myxomycetes. Five species in three different genera were represented by these specimens. The authors are not aware of any other records of this group of organisms from Norfolk Island, and the primary objective of the survey reported herein was to document more completely the myxomycetes present on the island.

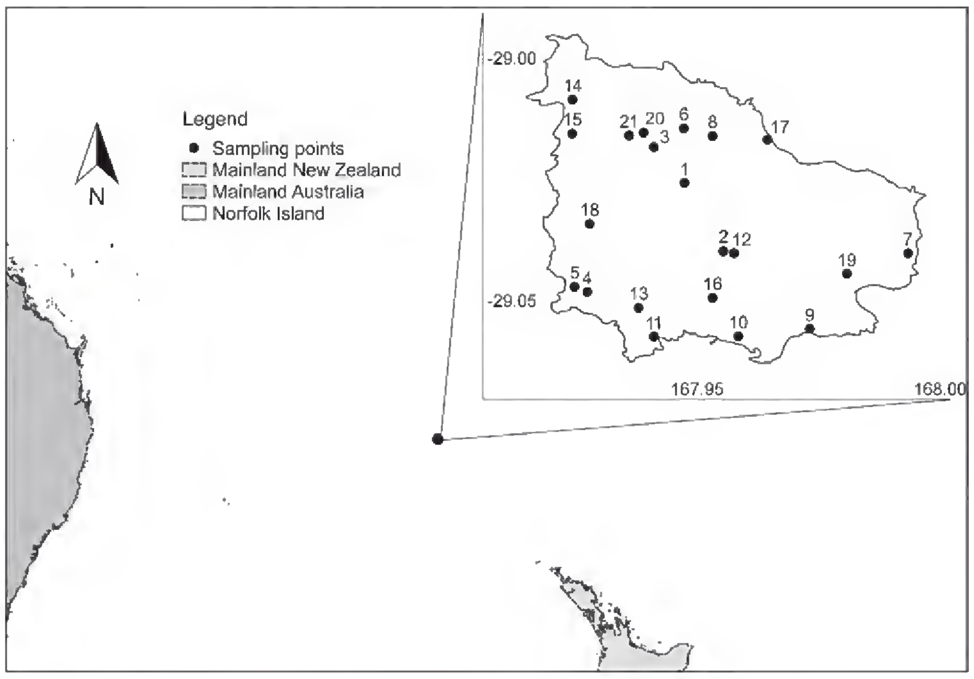


Fig. 1. Location of Norfolk Island in the South Pacific and locations of actual sampling sites on the island.

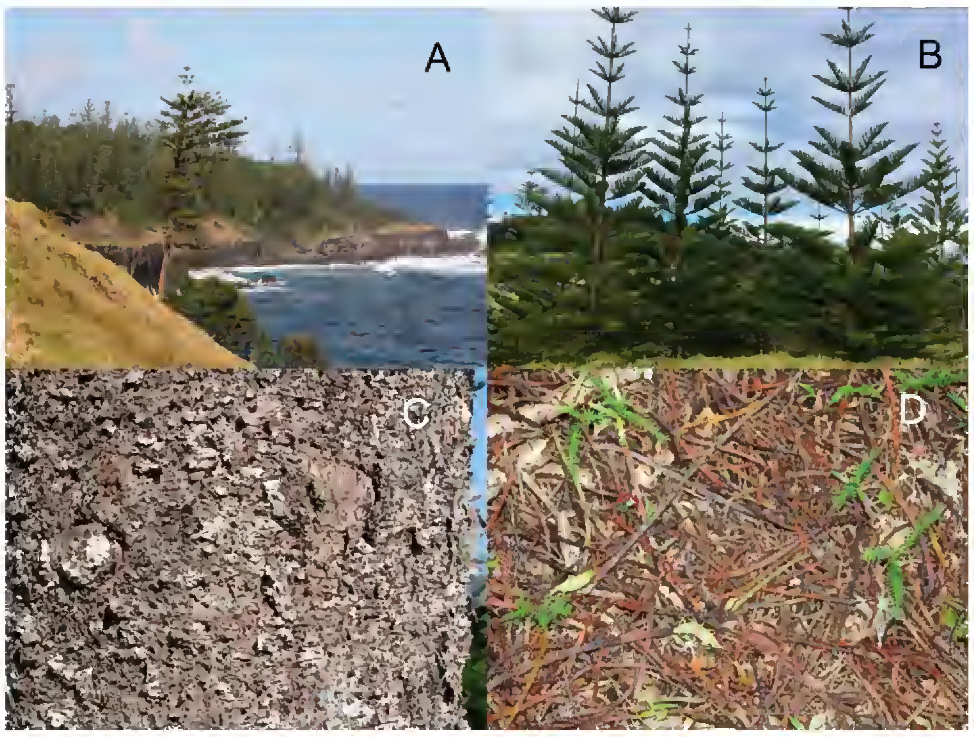


Fig. 2. (A) Coastline of Norfolk Island. (B) Young Norfolk Island pines. (C) Bark surface of Norfolk Island pine. (D) Forest floor leaf litter.

Materials and Methods

The survey for myxomycetes on Norfolk Island was carried out during a two week period in June 2019. The overall objective was to collect both specimens that had fruited in the field under natural conditions as well as specimens appearing in moist chamber cultures prepared with samples of dead plant material collected on the island. At each of the 21 sampling sites visited on the island, all of the substrates on which fruiting bodies of these organisms typically occur were examined in an opportunistic manner as described by Cannon and Sutton (2004). However, only three species were recorded from the field, so the primary focus of the survey was redirected towards collecting samples of various types of dead plant material from each study site. These samples included aerial litter (dead but still attached plant parts above the ground), ground litter (mostly dead leaves but also including other types of debris [Fig. 2D]), woody twigs on the ground, lianas and pieces of the dead outer bark from living trees (Fig. 2C). All samples were allowed to air-dry, mailed back to the Eumycetozoan Laboratory at the University of Arkansas and used to prepare a series of moist chamber cultures. The latter were prepared in the manner described by Stephenson and Stempen (1994) and consisted of disposable plastic Petri dishes (90 mm diameter) lined with filter paper. Enough sample material was placed in each dish to cover the bottom, and then this material was moistened with distilled water. After a period of approximately 24 hours, the pH of each culture was determined with a portable pH meter, after which excess water in the Petri dish was poured off. Moist chamber cultures were placed out of direct sunlight, maintained at room temperature, and checked for evidence of myxomycetes (either plasmodia or fruiting bodies) over a period of several months. When the fruiting bodies of myxomycetes were detected, they were removed, allowed to dry at room temperatures and placed in small pasteboard boxes for permanent storage.

The 21 sampling sites, with information on location (both latitude/longitude and locality on Norfolk Island), type of vegetation, and date visited, are listed below (Fig. 1).

Site 1 (29° 01' 33" S, 167° 56' 51" E), broadleaf forest, Botanic Garden, 11 June 2019; Site 2 (29° 02' 23" S, 167° 57' 19" E), urban setting, apartment at edge of the town of Burnt Pine, 11 June 2019; Site 3 (29° 01' 06" S, 167° 56' 28" E), Norfolk Island pine forest, Old Mountain Track along read to summit of Mt. Pitt, 12 June 2019; Site 4 (29° 02' 54" S, 167° 55' 39" E), Hundred Acres Reserve near Rocky Point, southern entrance, mixed broadleaf/Norfolk Island pine forest, 14 June 2019; Site 5 (29° 02' 50" S, 167° 55' 29" E), Hundred Acres Reserve near Rocky Point, northern entrance, mixed broadleaf/Norfolk Island pine forest, 14 June 2019; Site 6 (29° 00' 52" S, 167° 56' 50" E), Palm Glen, mixed broadleaf/Norfolk Island pine forest, 15 June 2019; Site 7 (29° 01' 01" S, 167° 59' 36" E), Two Chimneys Reserve, open broadleaf forest, 16 June 2019; Site 8 (29° 03' 21" S, 167° 57' 12" E), J. E. Road entrance to Norfolk Island National Park, broadleaf/mixed Norfolk Island pine forest, 16 June 2019); Site 9 (29° 03' 21" S, 167° 58' 24" E), Driver Christian Road above Bloody Bridge, roadside vegetation, 17 June 2019; Site 10 (29° 03' 26" S, 167° 57' 31" E), Bounty Street in Kingston, streamside vegetation, 17 June 2019; Site 11 (29° 03' 27" S, 167° 56' 28" E), Bumbora Reserve, coastal vegetation, 17 June 2019; Site 12 (29° 02' 25" S, 167° 57' 27" E), Queen Victoria's Garden, urban setting, 17 June 2019; Site 13 (29° 03' 05" S, 167° 56' 17" E), Point Ross Reserve, roadside vegetation, 17 June 2019; Site 14 (29° 00' 31" S, 167° 55' 28" E), Anson Bay Road along the northern coast of Norfolk Island, roadside vegetation, 18 June 2019; Site 15 (29° 05' 56" S, 167° 55' 27" E), along road in the northeastern portion of Norfolk Island, *Eucalypus* plantation, 18 June 2019; Site 16 (29° 02' 58" S, 167° 57' 12" E), Watermill Dam, streamside vegetation, 18 June 2019; Site 17 (29° 01' 00" S, 167° 57' 52" E), Cascade Reserve, roadside vegetation, 19 June 2019; Site 18 (29° 02' 03" S, 167° 55' 40" E), Barnabas Chapel, urban vegetation, 19 June 2019; Site 19 (29° 02' 40" S, 167° 58' 51" E), Ball Bay Reserve, coastal vegetation, 19 June 2019; Site 20 (29° 00' 56" S, 167° 56' 15" E), midway up the road to the summit of Mount Pitt, mixed broadleaf/Norfolk Island forest, 20 June 2019; Site 21 (29° 00' 57" S, 167° 56' 14" E), summit of Mount Pitt, forest edge, 20 June 2019.

Results

The samples collected on Norfolk Island were used to prepare a total of 356 moist chamber cultures. Two hundred and seventy-three of the cultures (77%) yielded plasmodia and/or fruiting bodies of myxomycetes. Eighty-three cultures showed no evidence of myxomycetes and 40 produced only plasmodia that did not form fruiting bodies. A total of 497 specimens were recorded from the moist chamber cultures. The appearance of more than a single species in a particular culture was not unusual, and five or more species were recorded from 14 different cultures. Collectively, the specimens obtained with the use of moist chamber cultures included 48 species belonging to 18 different genera. *Arcyria cinerea* was the single most abundant species, appearing in 69 different moist chamber cultures. Other species represented by specimens appearing in at least 20 cultures were *Didymium iridis* (45), *Physarum oblatum* (41), *Physarum pusillum* (40), *Physarum compressum* (34), *Physarum decipiens* (24), *Didymium squamulosum* (23) and *Lamproderma scintillans* (20). In addition to the specimens appearing in moist chamber cultures, three species (*Arcyria cinerea*, *A. denudata* and *Physarum flavicomum*) were represented by specimens collected in the field.

As a general observation, various types of ground litter (which ranged from broadleaf herbaceous litter to the leaves of Norfolk Island pine) were the most productive substrates, yielding 147 specimens. Lianas and aerial litter were the next most productive, each yielding 107 specimens. Twigs produced 75 specimens and 47 were recorded from bark. The numbers of samples collected for each type of substrate were not equal, so the numbers listed above do not allow absolute comparisons among the different substrates. However, they do provide some evidence of which substrates were the most favorable for myxomycetes.

Although the vast majority (ca 97%) of all specimens could be identified to the level of species, this was not possible in every instance. Most of the unidentified specimens were aberrant or poorly developed. Ten were members of the genera *Physarum* and *Comatricha*, which are sometimes difficult to identify even with relatively well-developed material. One specimen was problematic because it could not be immediately referred to any described species with which the first author is familiar. Unfortunately, it was represented by just two fruiting bodies.

All specimens of myxomycetes collected on Norfolk Island were deposited in the herbarium (UARK) of the University of Arkansas but ultimately will be transferred to the Australian National Herbarium (CANBR).

Annotated List of Species

In the list that follows, species of myxomycetes now known to occur on Norfolk Island are arranged alphabetically by genus and then species. Information is provided on the source of these records (either as specimens collected in the field [f] or specimens obtained from moist chamber [mc] cultures), the range of pH values of the culture(s) in which the specimen appeared if obtained in a moist chamber culture, the substrate upon which it was collected or cultured and the study site(s) from which the specimen itself or the sample of dead plant material used to prepare the moist chamber culture was obtained. Numbers given in parentheses are collecting numbers of the first author.

Arcyria cinerea (Bull.) Pers. (f, mc) Represented by 70 specimens, including one specimen (33710) collected in the field on decaying wood and 69 specimens (including 33721, 33724 and 33916) appearing in moist chamber cultures.

This species was recorded in moist chamber cultures from aerial litter, bark, ground litter, lianas and twigs (pH 5.2 to 8.1). The largest numbers of specimens were recorded from ground litter (24), lianas (20) and twigs (14), sites 1, 2, 3, 4, 5, 6, 7, 8, 11, 13 and 17.

Arcyria denudata (L.) Wettst. (f) Represented by one specimen (33709) collected in the field on decaying wood, site 4.

Arcyria insignis Kalchbr. & Cooke (mc) Represented by two specimens (33911 and 33970), both recorded on samples of the bark of a tree fern (pH 6.4 and 6.6), site 6.

Clastoderma debaryanum A. Blytt (mc) Represented by two specimens (including 34009), both recorded on twigs (pH 5.4 and 5.5), site 6.

Collaria arcyrionema (Rostaf.) Nann.-Bremek. ex Lado (mc) Represented by eight specimens (including 33802 and 34152), recorded from aerial litter, ground litter, lianas and twigs (pH 6.0 to 6.7), sites 4, 5, 6, 8 and 13.

Comatricha elegans (Racib.) G. Lister (mc) Represented by three specimens (including 33886), recorded on lianas and twigs (pH 5.9 to 6.5), sites 4 and 6. One specimen (33915) is problematic but appears to fit this species better than any other.

Comatricha laxa Rostaf. (mc) Represented by a single specimen (34248), recorded on ground litter (pH 6.1), site 6.

Comatricha tenerrima (M.A. Curtis) G. Lister (mc) Represented by a single specimen (34147), recorded on a liana (pH 6.4), site 4.

Craterium leucocephalum (Pers. ex J.F. Gmel.) Ditmar (f) This species was collected by Heino Lepp in 1995 and is represented by three specimens. These are HL1200, Botanic Garden, on leaf litter, 21 April 1995; HL1244, West Palm Glen Track, on leaf litter, 23 April 1995; and HL1334, Hundred Acres Reserve, on dead leaves in a *Eucalyptus* plantation, 1 May 1995. *Craterium leucocephalum* was not recorded in the survey carried out in 2019.

Cribraria confusa Nann.-Bremek. & Y. Yamam. (mc) Represented by a single specimen (34168), recorded on the fibrous bark of an unknown tree (pH 4.5), site 4.

Cribraria minutissima Schwein. (mc) Represented by two specimens (including 34149), recorded on the fibrous bark of an unknown tree (pH 4.3 and 4.4), site 4.

Cribraria violacea Rex (mc) Represented by 13 specimens (including 34025 and 34173), recorded from aerial litter, bark, ground litter, lianas and twigs (pH 5.7 to 8.0). Five specimens each were recorded from bark and twigs, sites 1, 3, 4, 5, 6, 7, 8 and 14.

Diachea leucopodia (Bull.) Rostaf. (mc) Represented by two specimens (including 34153), recorded from aerial litter and ground litter (pH 3.2 and 5.3), sites 12 and 15.

Diderma deplanatum Fr. (mc) Represented by seven specimens (including 33968 and 34174), recorded only from bark (pH 6.1 to 6.7), sites 3 and 4. Four of the seven specimens appeared on cultures prepared with samples of bark from Norfolk Island pine, so *Diderma deplanatum* appears to display a distinct affinity for this tree.

Diderma effusum (Schwein.) Morgan (mc) Represented by four specimens (including 34170 and 34175), recorded from bark and ground litter (pH 6.3 to 6.9), sites 2 and 6.

Diderma hemisphaericum (Bull.) Hornem. (mc) Represented by six specimens (including 34064 and 34155), recorded from aerial litter, ground litter and twigs (pH 6.0 to 6.8), sites 1, 4, 5 and 18.

Didymium anellus Morgan (mc) Represented by a single specimen (34275), recorded from ground litter (pH 6.5), site 6.

Didymium bahiense Gottsb. (mc) Represented by a single specimen (33741), recorded from ground litter (pH 6.4), site 6.

Didymium clavus (Alb. & Schwein.) Rabenh. (mc) Represented by two specimens (including 34003), recorded from aerial litter and bark (pH 6.6 to 7.3), sites 4 and 11.

Didymium difforme (Pers.) Gray (mc) Represented by two specimens (including 33766), recorded from aerial litter and a liana (both pH 6.9), site 1.

Didymium iridis (Ditmar) Fr. (mc) Represented by 45 specimens (including 33751, 34088 and 34107), recorded from aerial litter, bark, lianas, ground litter and twigs (pH 4.9 to 7.6), sites 1, 2,3, 4,5, 6, 7, 8, 11, 13, 16 and 17. This species was most common on aerial litter (24 specimens).

Didymium ochroideum G. Lister (mc) Represented by a single specimen (34065), recorded on ground litter (pH 6.9), site 4.

Didymium squamulosum (Alb. & Schwein.) Fr. & Palmquist (mc) Represented by 23 specimens (including 33713, 33776 and 34018), recorded on aerial litter, ground litter and lianas (pH 5.6 to 7.7). Twelve of the specimens were recorded on aerial litter, and nine were recorded on ground litter, sites 1, 3, 4, 5, 6, 7, 8, 11, 13, 16 and 20.

Echinostelium apitectum K.D. Whitney (mc) Represented by a single specimen (34227), recorded from the fibrous bark of an unidentified tree (pH 4.3), site 4.

Echinostelium minutum de Bary (mc) Represented by three specimens (including 33920), recorded from ground litter and twigs (pH 5.3 to 5.5), sites 6 and 15.

Enerthenema papillatum (Pers.) Rostaf. (mc) Represented by two specimens (including 34038), recorded from the fibrous bark of an unidentified tree (pH 4.3 and 4.5), site 4.

Lamproderma scintillans (Berk. & Broome) Morgan (mc) Represented by 20 specimens (including 33734 and 33748), recorded from aerial litter, ground litter and lianas (pH 5.7 to 8.1). Seventeen specimens (85%) were obtained from ground litter, sites 1, 4, 5, 6, 7, 8, 11, 13 and 18.

Licea operculata (Wingate) G.W. Martin (mc) Represented by two specimens (including 33930), recorded from twigs (pH 6.3 and 6.8), site 1. Both specimens are smaller than published descriptions of this species but conform in all other respects.

Macbrideola decapillata H.C. Gilbert (mc) Represented by five specimens (including 33732), recorded only on the bark of Norfolk Island pine (pH 6.1 to 6.8), sites 3, 4 and 8.

Macbrideola* cf. *oblonga Pando & Lado (mc) Represented by a single specimen (33717), recorded on a liana (pH 7.1), site 6.

Perichaena chrysosperma (Curr.) Lister (mc) Represented by three specimens (including 33975), recorded on aerial litter, ground litter and twigs (pH 6.0 to 6.7), sites 4 and 6.

Perichaena depressa Lib. (mc) Represented by 18 specimens (including 33736 and 33905), recorded on aerial litter, ground litter, lianas and twigs (pH 5.8 to 7.4), sites 1, 4, 5, 6, 11, 13 and 16. Half of the specimens (50%) were associated with ground litter and seven with lianas.

Perichaena dictyonema Rammeloo (mc) Represented by 10 specimens (including 33740 and 34144), recorded from aerial litter, ground litter, lianas and twigs (pH 6.0 to 7.6), sites 1, 5, 6, 7, 11, 13 and 16.

Perichaena pedata (Lister & G. Lister) G. Lister ex E. Jahn (mc) Represented by six specimens (including 33749 and 34016), recorded from ground litter and lianas (pH 6.8 to 7.0), sites 4 and 5. All of these specimens have a stipe that is shorter than what is given in published descriptions of this species but conform in all other respects.

Perichaena vermicularis (Schwein.) Rostaf. (mc) Represented by 22 specimens (including 33901, 34033 and 34128), recorded on aerial litter, bark, ground litter, lianas and twigs (pH 5.8 to 8.0), sites 1, 2, 3, 4, 5, 6, 11, 13, 18, 19, 20 and 21. Eight specimens were associated with ground litter.

Physarum aeneum (Lister) R.E. Fr. (mc) Represented by three specimens (including 34179 and 34225), recorded from twigs (pH 5.9 to 6.1), sites 1 and 4. This species is a new record for Australia. *Physarum aeneum* is not particularly common, and the majority of records are from North America (Martin & Alexopoulos 1969). However, the bronze-colored, glossy and usually wrinkled peridium is distinctive.

Physarum album (Bull.) Chevall. (mc) Represented by four specimens (including 33972 and 34150), recorded from lianas and bark (pH 4.4 to 6.9), sites 1, 4 and 8.

Physarum bivalve Pers. (mc) Represented by nine specimens (including 34142 and 34176), recorded on ground litter and twigs (pH 5.5 to 7.1), sites 6 and 13. Five of the nine specimens (56%) were recorded on the ground litter of Norfolk Island pine.

Physarum cinereum (Batsch) Pers. (f, mc) This species was first collected by Heino Lepp in 1995 and is represented by a single specimen. This is HL1333, Hundred Acres Reserve, on dead leaves in a *Eucalyptus* plantation, 1 May 1995. In the present study, it was represented by four specimens (including 33733 and 33935), recorded on aerial litter and ground litter (pH 6.2 to 7.0), sites 1, 6 and 10.

Physarum compressum Alb. & Schwein. (mc) Represented by 34 specimens (including 33726, 33908 and 34306), on aerial litter, lianas and ground litter (mc, pH 4.9 to 7.4), sites 1, 2, 4, 5, 6, 7, 8, 10, 11, 12, 13 and 20. Fourteen specimens were associated with aerial litter, 10 with ground litter, and nine with lianas.

Physarum crateriforme Petch (mc) Represented by three specimens (including 33764 and 34213), recorded on bark and ground litter from Norfolk Island pine (pH 7.2 to 7.3), sites 4 and 8.

Physarum decipiens M.A. Curtis (mc) Represented by 24 specimens (including 33803, 33982 and 34063), recorded on aerial litter, bark, ground litter, lianas and twigs (pH 5.4 to 6.9), sites 4, 5, 6, 8, 12 and 14.

Physarum flavocomum Berk. (f, mc) This species was first collected by Heino Lepp in 1995 and is represented by a single specimen. This specimen is HL1736A, Emily Bay, on a long-fallen branch lying on the ground, 18 May 1997. *Physarum flavocomum* was recorded in the present study when a yellow plasmodium, collected in the field from site 8 yielded numerous fruiting bodies when placed in a Petri dish.

Physarum gyrosum Rostaf. (mc) Represented by nine specimens (including 33739 and 34015), recorded on aerial litter (pH 5.4 to 7.9), sites 1, 2, 5, 6, 10, 13 and 19.

Physarum lakhanpalii Nann.-Bremek. & Y. Yamam. (mc) Represented by single specimen (34296), recorded on ground litter (pH 6.5), site 4. This species is morphologically similar to *Physarum decipiens* but can be distinguished from the latter on the basis of the clustered spores.

Physarum melleum (Berk. & Broome) Massee (f, mc) This species was first collected by Heino Lepp in 1995 and is represented by two specimens. These are HL1332, Hundred Acres Reserve, on dead leaves in a *Eucalyptus* plantation, 1 May 1995 and HL1335, on dead leaves in a *Eucalyptus* plantation, 1 May 1995. In the present study it was represented by six specimens (including 33884 and 34159), recorded on aerial litter and lianas (pH 6.5 to 7.2), sites 3, 4, 8 and 20.

Physarum oblatum T. Macbr. (mc) Represented by 41 specimens (including 33718, 33765 and 34156), recorded on aerial litter, ground litter, lianas and twigs (pH 5.2 to 7.7), sites 1, 2, 3, 4, 5, 6, 7, 8, 12 and 15. Sixteen (39%) of all specimens were recorded from lianas.

Physarum pusillum (Berk. & M.A. Curtis) G. Lister (mc) Represented by 40 specimens (including 33750, 33885 and 34043), recorded on aerial litter, ground litter, lianas and twigs (pH 5.2 to 7.2), sites 1, 3, 4, 5, 6, 8, 12, 13, 15, 20 and 21. Almost half (45%) of all species were associated with ground litter.

Physarum roseum Berk. & Broome (f) This species was first collected by Heino Lepp in 1995 and is represented by two specimens. These are HL1229, West Palm Glen Track, on decaying wood, 23 April 1995; and HL1300, Bird Rock Track, on decaying wood, 30 April 19. It was not recorded in the survey carried out in 2019, although red plasmodia (which are a distinctive feature of *Physarum roseum)*, are in two moist chamber cultures. However, these did not produce fruiting bodies.

Stemonitis fusca Roth (mc) Represented by 17 specimens (including 33801, 33871 and 33918), recorded from aerial litter, ground litter, lianas and twigs (pH 5.4 to 7.4), sites 3, 4, 6, 7, 17 and 21. More than half (59%) of the specimens were associated with twigs. All of the specimens of this species recorded on Norfolk Island were *Stemonitis fusca* var. *nigrescens* (Rex) Torrend.

Stemonitis* cf. *herbatica Peck (f) This species was collected by Heino Lepp in 1995 and is represented by a single specimen (HL1199) on leaf litter in the Botanic Garden, 21 April 1995.

Stemonitis splendens Rostaf. (f) This species was collected by Heino Lepp in 1995 and is represented by a single specimen (HL1220) on underside of a fallen *Eucalyptus* trunk in a *Eucalyptus* planation along Anson Bay Road, 22 April 1995.

***Trichia* sp.** (mc) Represented by two specimens (33833 and 34300), recorded from ground litter (pH 6.0 and 6.1), site 6. Each specimen consisted of a single well-developed fruiting body. It seems likely that this species is undescribed, but there is not enough material to propose it as new to science. A brief description is given below.

Fruiting body a stalked sporangium, 0.8 mm high; *sporotheca* globose; *hypothallus* inconspicuous; *stalk* stout, dark, approximately 60 percent of the total height of the fruiting body; *peridium* thin, shiny, bright yellow; *capillitium* consisting of long, yellow threads, 3–4 µm in diameter, with scattered spines up to 4 um long; *spores* yellow in mass, 7.5–8.5 µm in diameter, very finely warted; *plasmodium* not observed.

Willkommlangea reticulata (Alb. & Schwein.) Kuntze (mc) Represented by two specimens (33981 and 34163), both recorded from twigs (pH 5.9 and 6.1), site 4.

Discussion

The almost complete absence of fruiting bodies of myxomycetes in the field on Norfolk Island was unexpected but presumably reflects the fact that there must have been relatively little rainfall during the weeks prior to our visit to the island, although May, June and July have an average of 130 mm or more of precipitation (https://www.climatestotravel.com/climate/norfolk-island). However, of these three months, June tends to the driest. Woody substrates were invariably very dry, even those portions in direct contact with the ground. Another factor may have been the fact that many of the larger woody substrates (mostly logs on the forest floor) were derived from Norfolk Island pine, and it is possible that the wood of this tree is not especially favorable for the growth and development of myxomycetes. Based on the extensive field experience of the first author, fruiting bodies appear to be relatively uncommon on the wood from some types of trees (e.g., *Betula* spp. [birch]) in the Northern Hemisphere). Why this is the case is unknown.

The survey effort on Norfolk Island clearly indicates the value of using moist chamber cultures to complement field collections when studying myxomycetes. In an earlier study on Christmas Island (Stephenson and Stephenson 2019), both methods were used. Although the number of field collections was appreciably higher than the total recorded on Norfolk Island, moist chamber cultures also were more productive. The mean number of species recovered per culture for Christmas Island was 2.2, whereas the comparable figure for Norfolk Island was 1.4. The total number of species now known from Norfolk Island (55) is less than the number reported for Christmas Island (69) but exceeds the totals reported for Cocos Island (41 species) by Rojas and Stephenson (2008), Mahé Island in the Seychelles (47 species) by Krivomaz et al. (2017) and Ascension Island (36 species) by Stephenson (2008). However, all of these numbers are lower than the 96 species and infraspecific taxa reported from La Réunion Island by Adamonyte et al. (2011).

Species of myxomycetes are known to show varying degrees of specificity for the substrates with which they are associated. For example, some species are almost always associated with ground litter, the dung of herbivores or the dead outer bark of living trees (Stephenson and Stempen 1994). *Arcyria cinerea*, the species represented by the largest number of specimens in the present study, displays very little substrate specificity, since it was recorded from every major type of substrate. In contrast, *Macbrideola decapillata* was recorded only from the bark of Norfolk Island pine. If the concept of niche is applied to myxomycetes, as described by Stephenson (1988), *A. cinerea* would be considered as having a broad niche whereas the niche of *M. decapillata* would be relatively narrow. As indicated in the information presented along with each species in the annotated checklist portion of this paper, some of the other species represented by more than a very few species appeared to display a preference for a particular substrate. For example, most specimens of *Cribraria violacea* were associated with bark or twigs (which have a thin bark), and the majority of specimens of *Physarum bivalve* were associated with ground litter. Interestingly, at least 15 of the species recorded from Norfolk Island were associated with substrates (bark, ground litter and twigs) derived from Norfolk Island pine, although in only the single instance mentioned above was the species in question restricted to this tree. However, the major point to be made in this context is that myxomycetes are not absolute generalists with respect to the substrates on which they are found.

Presumably, most of the species present on any isolated island are the result of long-distance dispersal by wind, but some species may have arrived along with the large-scale introductions of exotic (introduced) plants. For example, the number of exotic plants on Christmas Island actually exceeds the total of native plants, and much of Norfolk Island is occupied by non-native vegetation, including agricultural areas and *Eucalyptus* plantations.

Although the results obtained from numerous studies that have been carried out in various regions of the world have generated a large body of data on the distribution and ecology of myxomycetes, there are still many regions that remain understudied. These include numerous examples of isolated islands. The project reported herein represented an effort to characterize more completely the assemblage of species associated with one of those islands—Norfolk Island.

Acknowledgements

This project was supported in part by the Slime Mold Project at the University of Arkansas. Thanks are extended to Heino Lepp for making his unpublished records of myxomycetes from Norfolk Island available to the first author. Diana Wrigley de Basanta and Gabriel Moreno provided helpful comments relating to two of the species reported herein, and Carlos Rojas developed the image used for Figure 1. Collecting activities on Norfolk Island were carried out under the guidelines of permit NI 2018/16 issued by the Department of the Environment and Energy of the Australian Government.

References

Adamonyte, G., Stephenson, S.L., Michaud, A., Seraoui, E.-H., Meyer, M., Novozhilov, Y.K. & Krivomaz, T.I. (2011). Myxomycete species diversity on the island of La Réunion (Indian Ocean). *Nova Hedwigia* 92: 523-549. DOI: 10.1127/0029-5035/2011/0092-0523

Cannon, P., & Sutton, B. (2004). Microfungi on wood and plant debris. In: Mueller, G., Bills, B., Foster, M. (Eds.) *Biodiversity of Fungi: Inventory and Monitoring Methods.* Elsevier Academic Press, Burlington Massachusetts, pp. 217-239.

Krivomaz, T., Michaud, A., Stephenson, S.L. (2017). First survey of myxomycetes on Mahé Island in the Seychelles. *Nova Hedwigia* 104: 65-84. DOI: 10.1127/nova_hedwigia/2015/0289

Lado, C. (2005–2019). An online nomenclatural information system of Eumycetozoa [accessed 7 March 2020]. Available from: http://www.nomen.eumycetozoa.com.

Martin, G.W. & Alexopoulos, C.J. (1969). *The Myxomycetes*. University of Iowa Press, Iowa City.

Martin, G.W., Alexopoulos, C.J. & Farr, M. L. (1983). *The Genera of Myxomycetes*. University of Iowa Press, Iowa City.

Rojas, C. & Stephenson, S.L. (2008). Myxomycete ecology along an elevation gradient on Cocos Island, Costa Rica. *Fungal Diversity* 29: 117-127.

Stephenson, S. L. (1988). Distribution and ecology of myxomycetes in temperate forests. I. Patterns of occurrence in the upland forests of southwestern Virginia. *Canadian Journal of Botany* 66: 2187-2207.

Stephenson, S.L. (2009). First records of myxomycetes from Ascension Island. *Sydowia* 61: 105-115.

Stephenson, S.L. & Stempen, H. (1994). *A Handbook of Slime Molds*. Timber Press, Portland, Oregon.

Stephenson, S.L., & Stephenson, B.C. (2019). Distribution and ecology of myxomycetes on Christmas Island, Indian Ocean. *Phytotaxa* 416: 138-148.

Manuscript accepted 12 May 2020

Date of Publication:
June 2020

Cunninghamia
A journal of plant ecology for eastern Australia

The Royal
Botanic Garden
Sydney

ISSN 0727-9620 (print) • ISSN 2200-405X (Online)

Historic archives are critical for reconstructing the nature and distribution of lowland temperate grasslands in south–eastern Australia

Paul Foreman

Department of Ecology, Environment and Evolution, La Trobe University, Bundoora, Victoria, 3086, AUSTRALIA.
89042577@students.latrobe.edu.au

Abstract: The functional relationships between woody vegetation, climate, soils and disturbances like fire are complex and vary greatly between continents due to historical and environmental differences. In the temperate grasslands of lowland south–eastern Australia, it is hypothesised that the extent of treelessness was influenced by Aboriginal burning practices, although this remains highly contested. This study reconstructed a multi–bioregional–scale grass/tree boundary map across a large portion of central and northern Victoria from hundreds of historic plans, overlayed with the georeferenced observations of the earliest European accounts to test whether these grasslands were (a) more extensive than previously assumed, and (b) if there is evidence of the targeted, purposeful and frequent use of fire by Aborigines. The archival coverage was well–corroborated and identified extensive treeless 'plains' in unexpected areas compared with reconstructions based on climate–edaphic relationships alone. The historic accounts also served to shed light on the original nature of these treeless 'plains' as diverse and dynamic, and frequently dominated by Kangaroo Grass (*Themeda triandra*), implying a distinct influence of both frequent fire and people. However, while there is evidence of broad–acre Aboriginal fires in the collective historic accounts (including resistance to European intrusion), there remains a need for more in–depth and reliable historic case studies to clearly describe the use of fire by Aborigines that is inferred in the historic accounts studied here and commonly assumed by historians. The results lend support to treelessness driven by the dynamic interaction of 'bottom–up' and 'top–down' processes and that lowland temperate grassland distribution reconstructions across this region should be extensively corroborated or even derived exclusively from historic sources.

Keywords: historic archives, temperate grasslands, vegetation reconstruction, Aboriginal burning, 'bottom–up' and 'top–down' processes

***Cunninghamia* (2020) 20: 123–137**
doi: 10.7751/cunninghamia.2020.20.006

© 2020 Royal Botanic Gardens and Domain Trust

Introduction

At the global scale, terrestrial biome distribution is primarily driven by abiotic ('bottom–up') controls such as light, temperature, precipitation and potential evapotranspiration (Whittaker 1975; Polis 1999; Bond 2008). Grasslands and savannahs, which often have the climate potential to support woodlands and forest, are considered a major exception with biotic ('top–down') controls such as herbivory and/or fire exerting a major influence on their distribution (Bond *et al.* 2003, 2005; Bond 2005, 2008; Sankaran *et al.* 2005, 2008). However, the functional relationships between woody vegetation, climate and disturbances like fire are complex and vary greatly between continents due to historical and environmental differences (Lehmann *et al.* 2014). Non–linear thresholds and tipping–point interactions are particularly important (House *et al.* 2003), with some regions switching from being 'climate–dependent' to 'disturbance–dependent' ecosystems depending on rainfall (Sankaran *et al.* 2005, 2008; Hirota *et al.* 2011; Ratajczak and Nippert 2012; Van Nes *et al.* 2012). In Australia, this rainfall threshold varies between climate zones and, in the temperate south–east (>400 mm per annum), it is hypothesised that treelessness is controlled by the complex spatio–temporal interaction of 'bottom–up' and 'top–down' processes such as anthropogenic (Aboriginal) fire (see Foreman 2016). However, little is known of the original fire regimes in this region, and the impacts of Aboriginal fire on broader ecosystem change remains highly contested (Bowman *et al.* 2012), and poorly studied due to the limited range of research strategies (Lunt 2002).

Although there is evidence that Aborigines manipulated fire regimes (e.g. Clark 1983; Hallam 1989; Fensham 1997; Bowman 1998; Lunt 1998; Gammage 2011), a critique of the regional historic records underpinning popular 'grand' historical narratives reveals few unambiguous or direct observations (e.g. Stockton 1982; Bowman and Brown 1986; Fensham 1997; Cahir *et al.* 2016; Cahir & McMaster 2018). It is argued that interdisciplinary research integrating the physical (biophysical/ecological models) and social (anthropological/historical records) aspects of fire ecology and phytoecology promises to shed light on such debates (Swetnam *et al.* 1999).

The first step in this process must be to reconstruct an accurate picture of the extent and nature of lowland, temperate grasslands using the historic archives. Century–scale reconstructions of vegetation have become a common means of historic benchmarking used to systematically describe patterns of land–use change (e.g. Mills 1988; Fensham 1989; Fensham and Fairfax 1997; Brown 1998; Batek *et al.* 1999; Bickford and Mackey 2004; Bollinger *et al.* 2004; He *et al.* 2007). Reconstruction primarily involves the spatial interpolation over 'cleared' areas (or non–native vegetation cover; see Thackway and Lesslie 2006) based on resilient vegetation refugia, climate–edaphic models and expert opinion (e.g. Moore 1953; Costin 1954; Connor 1966; Croft 1999; Knight 2002; Parkes *et al.* 2003; Keith 2004). However, many studies are not well validated or corroborated by the historic archives (e.g. Lunt 1998). When historic data is used, it is often based on broad–scale historic plans (e.g. Woodgate and Black 1988 derived from on Everett 1869; also see Hoddle 1853), or restricted to particular areas that happen to have been intensively researched (e.g. Foreman 1996; Lunt 1997; Sinclair and Atchison 2012), or sophisticated bioregional hybrid reconstructions that use contemporary data to fill gaps in the available historic coverage (e.g. Fensham 1989; Fensham and Fairfax 1997; Bickford and Mackey 2004). Nevertheless, most broad–scale reconstructions used by provincial and national authorities to derive land–use change data that informs policy (e.g. Victorian pre–1750 'ecological vegetation classes' or EVCs in Parkes *et al.* 2003 and the Australia's "Native Vegetation Information System" NVIS 2018; also see Morgan *et al.* 2017) are highly fragmentary in terms of historic corroboration. While this may not be an issue for many ecosystems, for grassy biomes, where the influence of often dynamic 'top–down' processes are significant, century–scale change may have been enormous.

Broad–scale thematic reconstructions based primarily or exclusively on historic records have been attempted when targeting particular habitats or features that were finely mapped by early surveyors (e.g. saltmarsh: Bromberg and Bertness 2005; estuary: Van Dyke and Wasson 2005; wetland: Gimmi *et al.* 2011; grassland: Cousins 2001). The economic importance of native grasslands to the early European colonies of south–eastern Australia suggests that the vast archival resources, newly digitised, represent a promising candidate case study of century–scale land–use change, and for testing *a priori* assumptions around 'bottom–up' (e.g. soils) and 'top–down' (e.g. fire) processes.

This paper constructs a multi–bioregional composite grass/tree boundary map across a large portion of lowland Victoria from systematic interpretation of early survey plans and by georeferencing the routes taken and observations recorded by early European settlers and explorers (see methods in Fensham 1997; Fensham and Fairfax 2007; Silcock *et al.* 2013; Silcock 2014; Silcock and Fensham 2019). As part of a multi–disciplinary approach, this paper considers tests for two of the original nine hypotheses advanced by Foreman (2016): #1 – Corroborated historic records of grasslands in areas where trees are expected (>400mm per year), and; #9 – Historic records of targeted, purposeful and frequent use of fire by Aborigines.

In particular, the study aims to: (1) compile a multi–bioregional–scale historic grass/tree boundary composite map of treeless 'plains' (grasslands) from fine–scale historic plans; (2) corroborate the authenticity and accuracy of grass/tree boundaries with multiple independent historic sources; (3) show that the grasslands occur in areas where trees are expected; (4) compile a description of the structure and floristic composition of historic 'plains'; (5) discuss why the results are likely applicable more widely in lowland south–eastern Australia; (6) discuss how anomalies in grassland distribution may in part be due to Aboriginal burning and how this could be tested; and (7) assess for evidence of the targeted, purposeful and frequent use of fire by Aborigines.

Methods

Study Area

The lowland, mesic grasslands of south–eastern Australia occur in a broadly temperate region with a mean annual precipitation of 400–1,000 mm, comprising the Tasmanian lowlands, much of the Victorian lowlands, the Southern Tablelands and inland slopes of NSW and the Australian Capital Territory (<1,000 m ASL), and parts of the Mount Lofty Ranges in South Australia (see Foreman 2016). The focus in this paper is central Victoria, north of the Great Dividing Range, which lies mostly within the Victorian Riverina, Victorian Volcanic Plains (VVP) and Wimmera sub–bioregions (www.environment.gov.au). These regions have an elevation range of sea level to 700 m ASL and all three comprise flat and fertile mostly arable plains in mesic zones that have long been intensively developed for agriculture (Figure 1). The Riverina is predominantly a higher level flood plain of fluvial and lacustrine sediments including channel sands, levee banks of fine sandy clay and far floodplain clays created by Holocene to Pliocene (5 MYBP) palaeochannels intersected by active floodplains associated with modern watercourses. The VVP comprises newer cinder/scoria cones and lava flows of Holocene to Miocene origin (8.5 MYBP) plus numerous alluvial floodplains, lake deposits and scattered inliers of older sedimentary rocks (up to 490 MYBP). The Wimmera comprises a complex range of Holocene to Miocene fluvial and aeolian landscapes with strands of active alluvium associated with modern major watercourses; and higher level mostly very flat floodplain clays, and extensive subdued dunes, swales and sand plains, and some more developed aeolian dunes.

Historic grass/tree boundary mapping

A bioregional–scale historic grass/tree boundary map was created from over 500 historic plans (80% from the 1850's–1860's; earliest: 1843) with some reference to natural and cadastral features, and vegetation patterns. They were sourced from the 'Historical maps and plans collection series' held at the State Library of Victoria and the Public Records Office of Victoria, including: GOULB (River), MURRAY (River), Parish maps of Victoria, Agricultural Areas (AA), Pastoral Runs (RUN), Sydney Plans (SYDNEY), Geodetic Squares (GEOSQ), Feature Plans (FEATR), New Roads (NR), Pre–emptive Rights (PR), Sale Plans (SALE), and Proclamations (other) (PROC). Mapping resolution varied from fine (≤1:30,000; 16% of maps), to intermediate (>1:30,000 to 1:50,000; 48%), and broad (>1:50,000; 12%), with no scale given for the balance (23%).

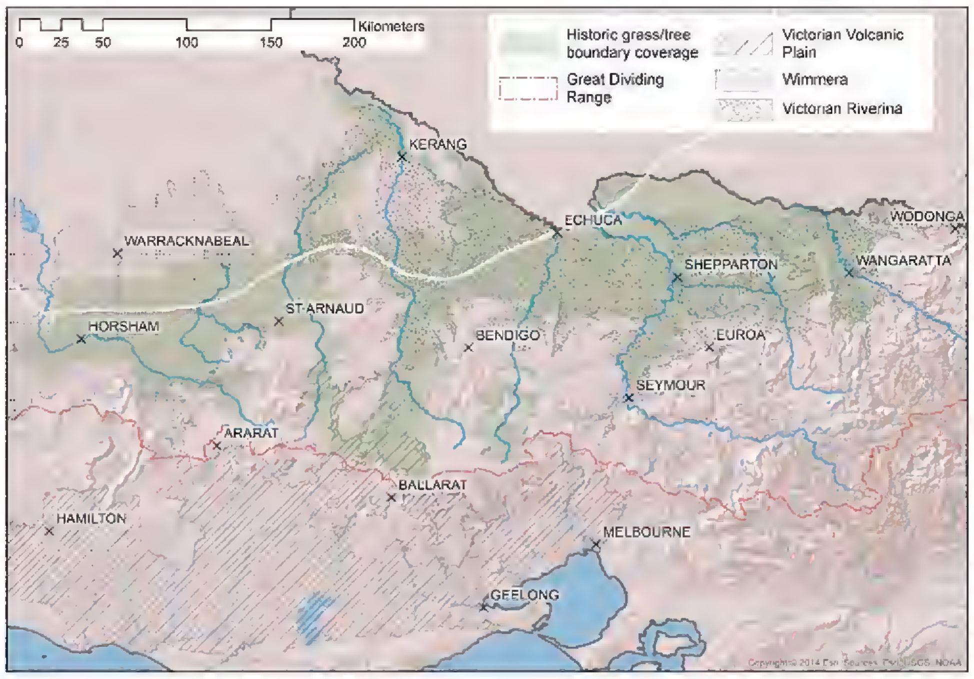


Fig. 1. Historic grass/tree boundary Study Area coverage across large portion of central and northern Victoria.

The plans were georeferenced in ArcGIS using the cadastre, rivers/creeks, hills and other prominent landscape features, and a composite vector layer was generated by manually digitising relevant vegetation boundaries, and polygons attributed by annotation, source plan and a grass/tree classification: (1) presence of 'plain', (2) absence of 'plain' (i.e. types other than grassland), and (3) Not specified, available or assessed. Both the 'plains' presence and absence categories were assigned a confidence level of (Yes) likely, or (Yes?) 'ambiguous–but–likely' and/or a 'grass/tree ecotone or mosaic'. In many cases, the grass/tree boundaries were explicit on the plans and, where absent, they were interpolated from the spatial arrangement of annotations. Those most frequently associated with grassland included: '*Plain*', '*Open Plain*', '*Grassy Plain*'; and for treed areas: '*Box Forest*', '*Open Forest*', '*Timbered with Box & Gum*'.

Confidence that the derived line work represented real grass/tree boundaries comes from the necessary intent of surveys, and corroboration with independent historical sources (especially the journals of explorers, overlanding pastoralists and other pioneers; e.g. Hawdon 1952; Mollison 1980; Clarke 1988; Mitchell 1838). It was the task of early surveyors to describe the "*quality*.... [and] *features of the country*... *as accurately as possible*... [including] *the coastline, rivers, streams, ranges and* ***other natural lines of country***" so that people attending land sales in Sydney, Melbourne or London had some understanding of what they were buying (Jacoby and Benwell 1989). It is possible the "*lack of*... *intensive natural features in Australia*" (c.f. England; Jacoby and Benwell 1989), and the fact that these pasture–lands were at the centre of the colony's early economic boom, further encouraged recording of grass/tree boundaries.

Open grassy 'plains' were distinctive and very important natural features of the landscape in these early times, especially where discrete grassland patches punctuated a dominant matrix of forest or woodland. Over 80% of the 'Pre–emptive Rights' established after 1838 in the Loddon, Rodney, Murray and Goulburn districts (Jacoby and Benwell 1990) shows proximity to such 'plains' as well as major water sources. The geography of these 'plains' was often corroborated between multiple plans – different series, dates and surveyors – and they were often given Aboriginal and/or European names. To illustrate, a section of the Goulburn Valley Highway near Murchison today passes through 'Raleigh's Plain', an area independently described – with progressively more detail – on four occasions between 1824 and 1863. Firstly, Bland's account of Hume and Hovell's 1824–25 expedition to Port Phillip (Hovell and Hume 1831; December 26, 1824) mentions 'Esthers Plains' on the Goulburn River around present day Nagambie. Secondly, Mitchell's journal on October 9, 1836 neatly captures the variegated grass/tree nature of this part of the Mid–Goulburn valley. Thirdly, one of the first formal surveys in the region (GOULB 22; Wedge 1851) annotates the boundary of 'Raleigh's Plain' with tree–like symbols. And fourthly, in one the area's first parish plans (Dargalong and Molka; Downey 1863), the boundary of this 'plain' is more precisely depicted with a dotted line representing the *'margin of forest and plain'*, with the annotations '*Open Plain, Good Soil*'; and '*Box Forest*', '*Open Box Forest*', '*Medium* [and] *Good Agricultural land*' respectively inside and out (see Fig. 6 in Foreman 2016).

Corroborated records of grasslands and evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Corroboration of this historic grass/tree boundary map was tested with journals of select early Europeans (1824 to 1843), comprising: two explorers (Hovell and Hume 1831; Andrews 1981; Mitchell 1838), three overlanders (Hawdon 1952; Walker 1838; Mollison 1980) and G.A. Robinson, the Chief Aboriginal Protector (Presland 1977; Clark 1988; 2014) (Table 1; Figure 2). These accounts represent the earliest published records for the region, and provide enough relevant detail for reliable georeferencing. This process was often aided by detailed local knowledge of the landscapes and environments traversed. The route and observation points for the eight journals were plotted using Google Earth based on distances, directions, and references to distinctive (often named) landmarks, features and milestones; expedition maps subsequently prepared by cartographers; and other contemporary interpretations that included corrections of apparent minor errors (e.g. Eccleston 1988).

The observations and remarks extracted from journals fell into six categories: (1) broad vegetation type; (2) contact with Aboriginal people/activity and proximity to major water sources; (3) presence of fire (including: Scale, Ignition, Age, Purpose and Vegetation); (4) presence and/or traditional use of tuberous plants; (5) Climate data (rain and lightning); and (6) 'plains' species, including saltbushes. Spatial precision fell into two categories – high to moderately precise observations at route points, and high to low precision remote observations. The vast majority of the observations were route points that were confidently georeferenced to within a 300 m – 3 km radius (~90%). Better precision was possible for some remote observations that referred to prominent known peaks or other spatially exact features. As grass/tree boundaries were important natural features in their own right, in many areas the boundaries recorded by early surveyors were also used to guide georeferencing in so far as was consistent with all other landmarks, features and milestones.

Recorder	*Type*	*Year*	*No. Days*	*No. Obs.*	*Observations of 'plains'*							*Reference*
					%Tot. Obs.	%Tot. Plains	(1)	(2)	(3)	*Map Tot.*	Map Corr. Adj.	
Mitchell	Explorer	1836	122	464	27	41	71%	14%	15%	*100%*	*81%*	Mitchell 1838
Robinson	Protector	1843	23	127	7	15	81%	15%	4%	*100%*	*93%*	Clark 1988
Robinson	Protector	1840	62	265	16	14	59%	39%	2%	*100%*	*82%*	Presland 1977
Walker	Overlander	1837	21	180	11	11	67%	15%	18%	*100%*	*77%*	Walker 1838
Hawdon	Overlander	1838	43	76	4	8	68%	24%	8%	*100%*	*84%*	Hawdon 1952
Mollison	Overlander	1837	164	258	15	7	50%	50%	0%	*100%*	*75%*	Mollison 1980
Hume & Hovell	Explorer	1824/25	53	250	15	2	100%	0%	0%	*100%*	*100%*	Hovell & Hume 1831; Andrews 1981
Robinson	Protector	1841	20	80	5	1	100%	0%	0%	*100%*	*100%*	Clark 2014
TOTAL	–	–	**508**	**1,700**	**100**	**100**	**74%**	**20%**	**6%**	***100%***	***89%***	

Table 1. Comparison of georeferenced journal records with the historic grass/tree boundary map covering a large portion of central and northern Victoria; The records were classified as follows: (1) corroboration between journal and map observations; (2) overlooked (mapped 'plains' apparently passed over and not recorded in journals); (3) error ('plains' observed in journals, but mapped as other vegetation types). The error component can be attributed to errors associated with both the journal observations and the historic grass/tree boundary map. An adjusted corroboration value was calculated by allocating a proportion of the overlooked to the corroborated value based on the corroboration proportion (e.g. TOTAL: 74 + [0.74x20] = 89).

The broad vegetation type category was further divided into (1) presence of 'plain', (2) absence of 'plain', and (3) vegetation type not mentioned or available. Consistent with the frequent delineation of grass/tree boundaries in the early survey plans, the designation of 'plains' from the journals occurred when abrupt transitions were noted or implied, typically from woodland/open forest to 'open plains' or 'downs'. The following example from G.A. Robinson provides a typical illustration: *"When leaving this forest belt, and opening out upon the plain, the change of scene was delightfully pleasant. Where Mr Hutton's house stands is a beautiful sight, with extensive plains* *before it"* (January 24, 1840; Presland 1977). However, the journals often also reflect the complex, variegated nature of the vegetation within these 'plains': *"the soil very rich, and well clothed with grass, with very few trees, certainly with no more than required for ornament, and they are not the gums, but wattles (mimosa of different kinds, forest oaks) honey–suckles (banksia), &c., and a great portion, is totally devoid of trees"* (May 27, 1837; Walker 1838). Where ever there was reasonable context from previous or later passages, 'plains' where sometimes interpreted from ambiguous phrases such as 'covered with thick pasture'. Mitchell (1838) repeatedly uses expressions like *"naturally adapted for agriculture.... and ready to receive the plough... or to depasture stock"* as a kind of euphemism for grassy, flat areas with little to no tree cover – areas widely regarded then as the 'best' agricultural land. 'Not mentioned' signified where classification could not be supported or where there was no clear reference to vegetation.

All fire records were classified as follows. (1) Scale: (i) Small/point, (ii) Broad–acre, (iii) Unknown. (2) Ignition (Broad–acre): (i) Non–anthropogenic Wildfire (lightning), (ii) European, (iii) Aboriginal, (iv) Unknown. (3) Age: (i) Current, (ii) Recent, (iii) Old. (4) Purpose: (i) Reaction to Europeans, (ii) Traditional, (iii) Unknown, (iv) European, (v) N/A (non–anthropogenic). (5) Vegetation: (i) 'Plain'/grassland, (ii) Other type, (iii) Unknown. Small/point fires created by Aborigines included domestic camp fires, ovens, fire–making techniques, ceremonial fire, burials, smoke signals, and burning game from trees. Reaction to Europeans included burning buildings and igniting vegetation as an act of 'frontier guerrilla warfare' to frighten, intimidate or retaliate against Europeans (see examples in Fensham 1997; also see Reynolds 1982, 1987). Unknown purpose was used where–ever it was difficult to classify broad–acre Aboriginal burning as traditional practices.

Comparison with past reconstructions and inverse texture effect (rainfall) threshold

The Victorian state wide 'Plains Grasslands and Chenopod Shrublands' pre–1750 EVC reconstruction comprises 10 EVC units, aggregates and mosaics, covering nearly 20,000 km^2, over 15 sub–bioregions (see Parkes *et al.* 2003; https://www.environment.vic.gov.au/). This layer was compared with both the historic grass/tree boundary map and the inverse texture effect 'threshold' for south–eastern Australia (mean annual rainfall >400 mm; Fensham *et al.* 2015) to determine the extent to which corroborated historic grasslands occur in areas where trees are expected. According to the inverse texture effect, woody cover is predicted to be higher on clay–rich soils (topsoil >40% clay) in the mesic areas of southern Australia because of their superior moisture–holding capacity and fertility (c.f. sandy soils), while in xeric environments, clay–rich soils tend to support less woody cover because of their water–retentive properties (i.e. soil water potential is extremely negative when soil moisture is low).

Bureau of Meteorology weather station monthly rainfall data was used to model a baseline, long–term mean annual rainfall surface across Victoria. The 2,287 Victorian weather stations were filtered to 691 (≥50 years of data since records began) and an inverse distance weighted (IDW) raster surface interpolated in ArcGIS with an output cell size of 0.112 ha (33.5 m^2). Similarly, a raster surface with the same output cell size was created from the historic grass/tree boundary mapping and combined with the rainfall raster generating >26.4 million cells covering a total area of >29,600 km^2 (excluding all areas where vegetation type was not mentioned or available). The results were plotted as the number of cells where 'plains' were present (grassland) or absent (woodland/other) by long–term mean annual rainfall (Figure 3).

Results

Historic grass/tree boundary mapping and corroborated records of grasslands

The historic grass/tree boundary map extended over ~33,400 km^2 of central and northern Victoria, spanning from near Horsham in the west to Wodonga in the east (nearly 15% of Victoria). The mapped region was mostly on Victoria's Northern Plains (75% of the Victorian Riverina, 79% of the Murray Fans and 37% of the Wimmera sub–bioregions), but also in the alluvial valleys and plains transecting the Goldfields (31%), the fringing slopes and low ranges associated with the Northern Inland Slopes (25%) and northern extensions of the VVP (6%; Figures 2 & 3). About a quarter of this coverage (~8,530 km^2, 26%) was classified as 'plain' or grassland, within a woody matrix characterised as predominantly 'variegated' (60–90%) or 'fragmented' (10–60%) (rather than 'relictual' <10%; McIntyre and Hobbs 1999). The highest proportion of grasslands occurred in the VVP, Wimmera and Victorian Riverina sub–bioregions (in decreasing order – 63% to 32%; Table 2).

Between the eight selected earliest accounts, a total of 1,700 observations over 508 travel days were georeferenced, mostly covering the Hume Highway (out bound) and Northern Plains (in bound) corridors established by Mitchell (1838). On average, the historic observers corroborated the existence of 'plains' in the historic grass/tree boundary mapping 74% of the time. The average rates of apparently overlooked and erroneous 'plains' records were respectively 20% and 6% – with the adjusted average corroboration rate, 89% (Table 1).

Comparison with past reconstructions and inverse texture effect (rainfall)

The comparison with Victoria's pre–1750 grassland EVC reconstruction reveals extensive areas of unexpected grassland insofar as they were outside areas previously mapped (>5,380 km^2, or 63% of the total historical 'plains' coverage). The area of overlap (37%) was almost entirely in the lower rainfall portions of the Wimmera and Victorian Riverina, while there were extensive 'new' grassland areas both west and east of the Campaspe River. In the west, these areas extended the known grassland regions south into the mid to upper valleys of the Wimmera, Avon/Richardson, Avoca, Loddon and Campaspe Rivers. In the east, an extensive network of discrete and sometime large 'plains' were mapped over the Corop Lakes region, and in the lower to mid valleys of the Goulburn, Broken/Boosey, Ovens/King and Murray systems. Two particularly large anomalies occurred on newer volcanic plateaus in the Upper Campaspe and in the Upper Loddon ('Moolort Plains'). Conversely, areas of pre–1750 grassland not supported by the historic mapping were widespread (>1,620 km^2 or 34% of the total pre–1750 grassland EVC reconstruction) but restricted to the lower rainfall west and north–west. Almost all of the 'new' grasslands occurred where mean annual rainfall exceeds 400 mm, in apparent contravention of the 'inverse texture effect' (see Discussion; Fensham *et al.* 2015) (Figures 2 & 3).

The rainfall raster analysis showed the clear dominance of woodland/other vegetation rising sharply in regions with >400 mm mean annual rainfall. While grassland was most dominant in regions receiving <400 mm, it was still consistently present in higher rainfall regions. The mean proportion of grassland cells was 19.96% between 425 and 800 mm, although confidence declined above ~650 to 700 mm where historic maps were less available (Figure 3).

Historic Mapping(ha) =		**Total**	**'Plains'**	**'Plains'**	**'Plains'**	**Other, N/A**	**–**	**%Matrix (Woodland)**	**%'Plains'**
Pre–1750 Reconstruction(ha) =		**–**	**–**	**Other 'New'**	**Grassland Overlap**	**Grassland Error, N/A**	**Grassland**		
Victorian Sub–bioregions	Central Victorian Uplands	77,609	13,203	13,203	–	–	–	75%	25%
	Goldfields	408,186	28,911	28,888	24	1	25	90%	10%
	Greater Grampians	4,279	–	–	–	–	–	N/A	N/A
	Lowan Mallee	2	–	–	–	–	–	N/A	N/A
	Murray Fans	344,532	36,574	35,552	1,022	5,052	6,074	89%	11%
	Murray Mallee	70,248	13,107	12,086	1,021	2,638	3,659	79%	21%
	Northern Inland Slopes, Upper Slopes	140,824	4,070	3,768	302	309	611	97%	3%
	Victorian Riverina	1,412,863	411,751	213,990	197,761	65,367	263,128	68%	32%
	Victorian Volcanic Plain	144,263	81,596	79,295	2,301	388	2,689	37%	63%
	Wimmera	742,655	264,056	151,792	112,265	88,902	201,167	59%	41%
	Grand Total	**3,345,462**	**853,269**	**538,574**	**314,695**	**162,658**	**477,353**	**71%**	**29%**
		–	26%	16%	9%	5%	14%	–	–

Table 2. Breakdown of historic grass/tree boundary mapping by Victorian sub–bioregions, 'plains' classification and the Victorian pre–1750 EVC grasslands reconstruction. Highlight shows extensive 'new' grasslands identified in the historic mapping.

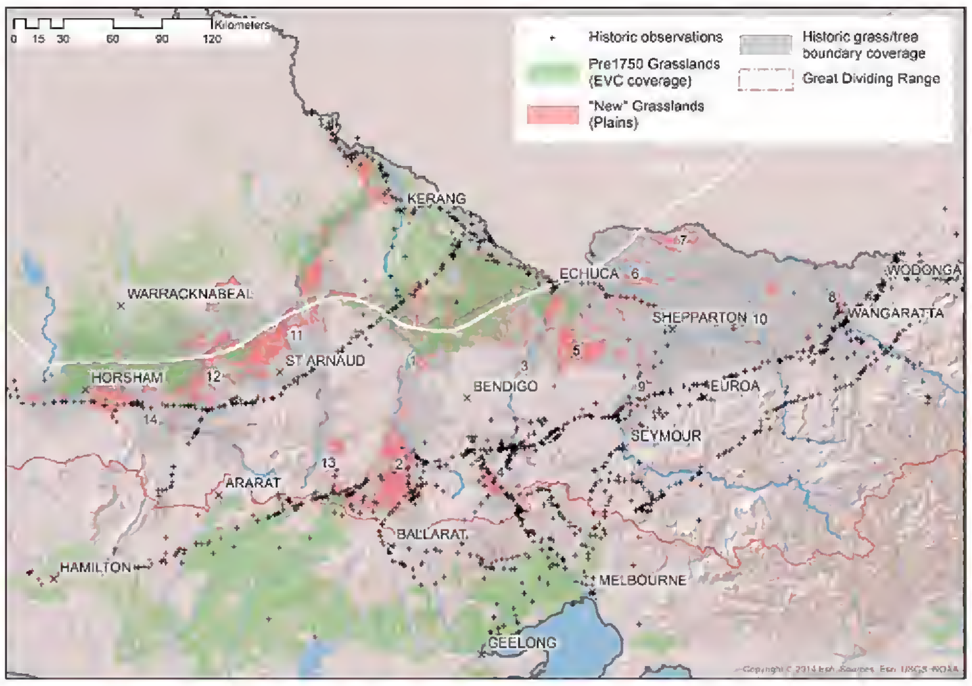


Fig. 2. Historic grass/tree boundary mapping across central and northern Victoria overlayed with the pre–1750 grassland EVC reconstruction (green) and all georeferenced historic observations; Total extent of historic mapping (dark grey) and 'new' historic grasslands (red) in unexpected regions denoted by river basins: 1 Mid Loddon, 2 Upper Loddon ('Moolort Plains'), 3 Mid Campaspe, 4 Upper Campaspe, 5 Corop Lakes, 6 Lower Broken/Goulburn, 7 Mid Murray, 8 Lower Ovens, 9 Mid Goulburn, 10 Mid Broken/Boosey, 11 Mid Avoca, 12 Avon/Richardson, 13 Upper Avoca, 14 Mid/Upper Wimmera.

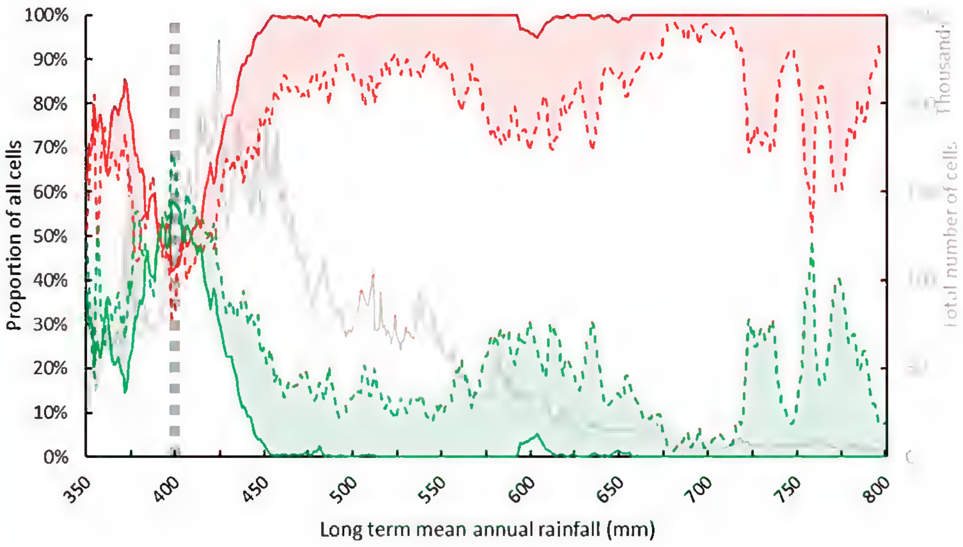


Fig. 3. Plot of raster grid cells of treeless 'plains' or grasslands (green) and woodland or other woody dominated vegetation types (red) as derived from (1) Pre–1750 EVC reconstruction ('Plains Grasslands and Chenopod Shrublands' – solid lines) and (2) historic grass/tree boundary mapping (dashed lines) across central and northern Victoria verses long term mean annual rainfall (mm). Secondary axis shows total number of cells (grey solid line) and all lines are fitted trendlines (2 point moving average). Graph shows the dominance of woodland/other vegetation types >400 mm but the consistent presence of some grassland throughout mesic regions. Shading denotes significant under and over estimates of grassland and woodland respectively in the EVC reconstruction c.f. the historic mapping.

Nature of historic plains and species observations

Although the vast majority of the historic observations provide brief and often ambiguous passing reference to grasslands, some make specific mention of the structure, spatial patterning, dynamics and botanical composition of the 'plains' at this early time. A list of 111 plant records was compiled from 60 observations that could be directly linked to 'plains.' Murnong or Yam Daisy (*Microseris* spp.) was the most frequently recorded geophyte, but there were many others including taxa from Asphodelaceae (incorporating *Caesia, Bulbine, Dianella* and *Tricoryne*), Orchidaceae (*Caladenia, Diuris,* and *Pterostylis*) and Colchicaceae (*Burchardia* and *Wurmbea*). Kangaroo Grass (*Themeda triandra*) was the most frequently noted tussock grass, and while various others were mentioned, it is difficult to be sure of either genus or species (possibly *Austrostipa* spp. and *Poa* spp.). These were followed by a range of small trees, herbs, shrubs, (saltbushes in the drier north), and larger sometimes readily identified trees (Table 3). This modest historical list, derived from scattered observations, could easily be expanded with further assessment of the historic record (both elsewhere in the region and from later decades), but it will suffice to draw out some significant patterns and to provide a sense of what the first Europeans actually saw in these environments.

Most of these flora observations were clustered in three regions: the relatively mesic Upper Campaspe (in the vicinity of Redesdale); the Upper Loddon plains (between Moolort and Creswick); and the drier Northern Plains region (south–west of Pyramid Hill) (see Figure 2), and it is useful to contrast each to highlight ecological patterns.

The overlander Mollison (1980) first visited the Upper Campaspe Plains in July 1837 and G.A. Robinson in January 1840 (who also recorded the testimonies of pastoralists, Hutton and Munroe, from previous winters; Presland 1977). Approaching from the east in wet conditions, Mollison describes a 'plain' on an elevated volcanic tableland, firstly dominated by gilgai soil and then another of "*better appearance and firmer ground*". But rather than being dominated by tussock grasses, both Mollison and Robinson report the abundance of *Microseris*: "*these plains abound with the root called by the natives at Port Phillip, 'Murnong'*", "*Mr. Munro said there were millions of murnong or yam, all over the plain* [in July 1838]", and "*Mr Hutton said* [in winter 1838/9] *the ground yielded abundance of roots (murnong).*" In contrast, Robinson's summer observations of the same area refer to "*verdant pasture*", the great abundance of "*Anthistiria or oat grass* [*Themeda triandra*]….. *all over the country*", interspersed with flowers: "*a carpet of blue there, one of yellow and again of white; the buttercups had a fine appearance.*" In composite, these records paint a picture of a highly dynamic landscape apparently dominated in the cool–season by a geophyte (and the apparent absence or paucity of grasses) and later succeeded by the summer–active (C4) Kangaroo Grass and a variety of interstitial, spring and summer wildflowers. Given that this picture appears to have been reported over three seasons in succession (1837–39), frequent (pre–cool–season) burning provides the most likely functional explanation consistent with the evidence. This description is further supported by the first overlander to retrace Mitchell's route across the Upper Campaspe Plains in May 1837, T. Walker (1838), who noted near Redesdale that: "*over most of* [the plain] *the grass has been lately burnt, which gives It a barren, naked, black, and unpleasant appearance; but in spring it must look very well, as there is evidently a tolerable sward of grass.*"

A similar picture emerges for the Upper Loddon (volcanic) Plains when visited by G.A. Robinson in February and March 1840 (Presland 1977), and earlier Mitchell (1838) outbound in September 1836. This much broader volcanic landscape was also variegated, but with numerous distinctive 'bare' (treeless) scoria cones. Importantly, it was also only during summer that they noted 'plains' dominated by *Anthistiria* or Kangaroo Grass. On a number of occasions Robinson notes "*herbs amongst the grass*" and in at least one place "*a dominant shrub.. myrtle*" (possibly *Calytrix tetragona*). Other shrubs and subshrubs noted elsewhere included *Discaria pubescens*, *Rhytidosporum procumbens* and *Acacia paradoxa* or *A. acinacea*. In places Robinson noted that interstitial herbs were so abundant the "*plains were mottled or carpeted with flowers in full blossom; patches of 1 to 2 acres of everlasting flowers, and patches of an acre or more of yellow ditto, and other patches of [ ] or the beautiful blue flower.*" The herbs noted included Murnong (*Microseris* spp.), *Pelargonium rodneyanum* and the terrestrial orchids *Caladenia dilatata* and *Diuris aurea*.

Recorder	***Life–form (see details below)***									
	Tree	Small Tree	Parasite	Shrub	Halophyte	Tussock Grass	Root/ Geophyte	Herb (Forb)	No. of Life–forms	**Grand Total**
Hawdon 1838	–	1	–	1	1	2	1	–	(5)	**6**
Hume and Hovell 1824	–	–	–	–	–	2	–	1	(2)	**3**
Mitchell 1836	–	1	–	6	1	5	12	1	(6)	**26**
Mollison 1837	–	–	–	–	–	–	2	–	(1)	**2**
Robinson 1840	7	10	–	2	–	14	11	11	(6)	**55**
Robinson 1843	3	6	1	–	5	4	–	–	(5)	**19**
Grand Total	**10**	**18**	**1**	**9**	**7**	**27**	**26**	**13**	**(8)**	**111**

Table 3. Breakdown of direct grassland ('plains') flora observations in early historic accounts across a large portion of central and northern Victoria. Shows the high frequency of Tussock Grasses like Kangaroo Grass (*Themeda triandra*; 15 records) and Root/Geophytes like Yam daisy or 'Murnong' (*Microseris* spp.; 14 records).

Life–form	Historic reference	Putative Latin names
Tree	‘Box, gums, stunted gum, stringybark, peppermint’	various *Eucalyptus* spp.
Small Tree	‘Blackwood’	*Acacia melanoxylon*
	‘Hee Oak’	*Allocasuarina luehmannii*
	‘She Oak’	*A. verticillata*
	‘Pine Trees’	*Callitris* spp.
	‘Cherry Tree’	*Exocarpos cupressiformis*
	‘Honeysuckle’	*Banksia marginata*
Parasite	‘pendant in the branches of Hee oak’	*Lysiana exocarpi, Muellerina eucalyptoides or Amyema* spp.
Shrub	‘Mimosa, wattle, or yellow–wreathed acacia’	*Acacia* spp., *A. paradoxa, A. acinacea*
	Campylanthera ericoides	now *Rhytidosporum procumbens*
	Discaria australis	now *D. pubescens*
	‘Myrtle’	possibly *Calytrix tetragona*?
	other ‘small bushes scattered over the plains’	Unknown
Halophyte	‘Banilla’	*Chenopodiaceae incl. Atriplex* spp.; Maireana spp.
	Pigs face’	*Disphyma crassifolium, Carpobrotus* spp. or *Sarcozona praecox*
	‘Salsuginous’ plants	various families
Tussock Grass	‘*Anthisteria* or oatgrass’	*Themeda triandra*
	‘an *Andropogon* allied to *A. bombycinus’*	probably *Cymbopogon obtectus*, last coll. 1887
	‘long forest grass’	possibly *Poa labillardierei*
	‘wiry grass’	possiby *Austrostipa* spp.
	‘thickly grassed’ or ‘Rib–grass’	*Poaceae* spp.
Root/Geophyte	‘Murnong… yams… small root of the cichoraceous plant tao usually found growing on the plains with a bright yellow flower…. yellow with the flowers of the cichoraceous plant tao whose root small as it is constitutes the food of the native women and children’	*Microseris* spp. incl. *M walteri*
	‘Turrac, a small tuberous root eaten by the natives, having a red flower resembling a geranium’	*Geranium* spp. or *Pelagonium* spp.
	Anguillaria dioica	now *Wurmbea dioica*
	‘white *Anguillaria*’	*Wurmbea* spp.
	‘a new bulbine with a delicate yellow flower being perfectly distinct from both the species described by Brown’	*Bulbine suavis* now *B. glauca*
	Caladenia dilatata	No change
	Diuris aurea	*Diuris* spp.
	blue, yellow, pink, brown Caladenia’	various *Caladenia* spp.
Herb (Forb)	*Picris barbarorum*	No change
	Ranunculus spp.	various *Ranunculus* spp.
	‘blue.. yellow… white everlasting flowers’	various *Asteraceae* spp.
	other ‘blooms [and] herbage… amongst the grass’	Various families

The contrast of the description from the drier Northern (Riverine) Plains region could not be more stark. Overlander, Hawdon (1952) visited the ‘plains’ between Pyramid Hill and the Loddon River in February 1838, Mitchell (1838) passed through in June 1836 and G.A. Robinson in April 1843 (Clark 1988). This is the region where Mitchell’s rapturous wet–winter “*sublime… verdant plains*” declaration contrasts with Hawdon’s pragmatic and sober dry–summer opinion: “*land of the worst description*” with its thin sprinkling of grass and “*vulgar*” pig’s face everywhere. Hawdon later mentions “*small bulbous roots* [that Corellas] *dig out of the plains*” and “*small bushes scattered over the plain,*” the latter likely a reference to chenopods. Mitchell mentions a geophyte near Mount Hope (*white anguillaria,*” *Wurmbea* spp.); however, scant mention of these life–forms suggest they may not have been overly abundant or dominant in this region. Robinson’s Autumn description of the same area five years later is broadly similar: “*the plains are thinly grassed [wiry grass* possibly *Austrostipa spp.] and are studded with clumps of* [various types of] *Banilla & pigs face* [interspersed] *through belts of stunted box forest, a few pine trees & numerous Hee Oak.*” Banilla is probably “Barilla” which is Spanish for halophyte and is likely to mean “saltbush” in this context. Interestingly, both Mitchell and Robinson tuned into an ecotonal shift in the vegetation as they moved south–west towards the Loddon River. Mitchell mentions “*a fine plain”* of Kangaroo Grass suggesting it was the first time he had seen this species for some time and/or that it had not been recently burnt, and Robinson pointed out that the same area was no longer dominated by chenopods.

Evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Of the 1,700 discrete observations of events or landscape features (Table 1), only 54 appear to have been broad–acre fires that mostly occurred in summer and Autumn (80%) – a further 48 fires were considered small/point fires or the scale was not specified. Of these 54, nearly half were attributed to Aboriginal ignition (26), while the rest were unknown, but could include a mix of Aboriginal and non–anthropogenic fires. Only one fire was explicitly recorded as a wildfire caused by a non–anthropogenic source (lightning) and two fires were lit by pastoralists. Aboriginal burning (26 fires) comprised 10 of unknown/unspecified purpose, and 10 were a reaction to Europeans (June to December), leaving six for 'traditional purposes' such as promoting fresh grass for game (Table 4).

Lightning was occasionally mentioned – primarily between November and March – the same period when most broad–acre fires were reported and when the vegetation is typically driest and most flammable. However, lightning coinciding with broad–acre fires was noted on only one occasion ("*Thunder and lightning this morning, the fires on the hills had a very singular effect*" February 14, 1841; Clark 2014), and on none of the days when the historic observers were thought to be describing broad–acre Aboriginal burning. The only example of likely traditional burning timed before rainfall was reported by G.A. Robinson three days after a fire was started at Bontharambo station (February 11–14, 1841; Clark 2014) when he was some distance up–stream on the Ovens River near present day Myrtleford.

	All Historic Observations (No.)	Observers (No.)								Lightning	Rainy Days	Tuberous Plants	Scale			
		Hawdon 1838	Hume & Hovell 1824	Mitchell 1836*	Mollison 1837	Robinson 1840	Robinson 1841	Robinson 1843	Walker 1837				Small/Point	**Broadacre**	Unknown	**Total**
Jan	**140**	46	16	-	-	78	-	-	-	3	6	6	5	6	-	**11**
Feb	**230**	30	-	-	-	120	80	-	-	3	4	7	17	11	1	**29**
Mar	**118**	-	-	-	-	67	-	51	-	4	5	1	9	5	1	**15**
Apr	**76**	-	-	-	-	-	-	76	-	-	-	-	1	1	-	**2**
May	**177**	-	-	-	-	-	-	-	177	1	4	-	-	10	-	**10**
Jun	**112**	-	-	104	5	-	-	-	3	-	2	3	5	5	-	**10**
Jul	**219**	-	-	132	87	-	-	-	-	-	11	2	2	1	1	**4**
Aug	**27**	-	-	-	27	-	-	-	-	-	1	-	-	1	-	**1**
Sep	**138**	-	-	125	13	-	-	-	-	1	2	6	-	-	-	**-**
Oct	**136**	-	-	103	33	-	-	-	-	-	4	1	-	1	-	**1**
Nov	**139**	-	95	-	44	-	-	-	-	2	2	-	-	3	4	**7**
Dec	**188**	-	139	-	49	-	-	-	-	1	1	-	2	10	-	**12**
Tot.	**1,700**	**76**	**250**	**464**	**258**	**265**	**80**	**127**	**180**	**15**	**42**	**25**	41	**54**	7	**102**

	Broadacre (Sc.)																						
	Ignition											Age		Purpose				Hist. Obs. (Veg.)			Hist. Map (Veg.)		
					Aboriginal (Ig.)																		
					Purpose			Trad&Unk.															
								Hist. Map (Veg.)															
	Wildfire	European	**Aboriginal**	Unknown	Reaction	**Traditional**	**Unknown**	Plain	Other (Wdld)	Unknown	**Total**	Current	Recent/Old (past)**	Reaction	Traditional	Unknown or N/A	Pastoralists	Plain	Other (Woodland)	Unknown	Plain	No (Woodland)	Not Mapped or Unk.
Jan	-	-	5	1	-	1	4	1	3	1	**5**	3	3	-	1	5	-	-	-	6	1	3	2
Feb	1	1	6	3	-	2	4	3	-	3	**6**	10	1	-	2	8	1	2	2	7	3	-	8
Mar	-	1	2	2	-	1	1	1	-	1	**2**	1	4	-	1	3	1	-	-	5	2	-	3
Apr	-	-	1	-	-	-	1	1	-	-	**1**	-	1	-	-	1	-	-	-	1	1	-	-
May	-	-	-	10	-	-	-	-	-	-	**-**	-	10	-	-	10	-	3	7	-	3	2	5
Jun	-	-	2	3	2	-	-	-	-	-	**-**	2	3	2	-	3	-	2	1	2	2	-	3
Jul	-	-	1	-	1	-	-	-	-	-	**-**	1	-	1	-	-	-	-	-	1	-	-	1
Aug	-	-	-	1	-	-	-	-	-	-	**-**	-	1	-	-	1	-	-	-	1	-	-	1
Sep	-	-	-	-	-	-	-	-	-	-	**-**	-	-	-	-	-	-	-	-	-	-	-	-
Oct	-	-		1	-	-	-	-	-	-	**-**	-	1	-	-	1	-	1	-	-	-	-	1
Nov	-	-	3		3	-	-	-	-	-	**-**	3	-	3	-	-	-		2	1	-	-	3
Dec	-	-	6	4	4	2	-	-	-	2	**2**	8	2	4	2	4	-	2	8	-	-	-	10
Tot.	1	2	**26**	25	10	**6**	**10**	6	3	7	**16**	28	26	10	6	36	2	10	20	24	12	5	37
	54				**26**							**54**		**54**				**54**			**54**		

Table 4. Historic observations of fire by Scale, Ignition (Broad–acre), Age (see Fensham 1997), Purpose and Vegetation (from historical observers and historic mapping). *Excludes July 25 to Sept 10 (far south–west Vic.); Mitchell's journal likely has no records of broad–acre fire because the expedition took place over the cool–season, in a wet year (June to October).**Date adjusted for 'past' fires where supported by text.

Discussion

Corroborated historic grass/tree boundary mapping

The historic grass/tree boundary map for a large portion of central and northern Victoria derived here from hundreds of plans dating from the early decades of the Port Phillip colony is the first multi–bioregional, thematic vegetation reconstruction in south–eastern Australia derived exclusively from the historic archives. The map documents in fine detail, extensive tracks and complex mosaics of treeless 'plains' covering over a quarter of the region and is well corroborated not just by those creating the maps, but also by the earliest Europeans who journaled their routes and observations. It is not surprising that Mitchell (1838) and Hume and Hovell (Andrews 1981) where the most assiduous in daily recording their observations, including grassy 'plains,' given their brief as explorers and the 'Australia Felix' vision built on the promise of pastoral exploitation. It also makes sense that the journals of G.A. Robinson proved highly corroborative because of his position as Chief Aboriginal Protector and prolific writings. It is possible the slightly lower corroboration rate for the overlanders is explained by their private entrepreneurial agenda, being either less interested in the landscape they passed through and generally lacking specialist skills around botany, anthropology and linguistics. The map represents a compelling evidence base for widespread historic grasslands – not previously mapped – across the Study Area.

Comparison with past reconstructions and inverse texture effect (rainfall)

The multi–bioregional historic reconstruction developed here contrasts markedly with previous reconstructions of native grassland distribution in the Study Area. Extensive 'new' areas of grassland were identified throughout, especially in the mesic regions (>400 mm per annum; Figure 2). This divergence is significant considering Victoria's pre–European reconstruction (Parkes *et al.* 2003) was largely based on climate–edaphic models consistent with the 'inverse texture effect' (with the notable exception of the VVP – see below; Fensham *et al.* 2015). The results suggests grassland was likely widespread in similar regions elsewhere – i.e. across the inland mesic portions of NSW (see Keith 2004) and indeed patchily throughout the slopes, tablelands and coastal hinterlands of the south–eastern mainland and Tasmania (e.g. Ellis 1985; Fensham and Fairfax 1996, 2006; Butler *et al.* 2006, 2014; Bowman *et al.* 2013; Karskens 2019). All of the early Europeans featured in this study (and many others) – that traversed the corridor between Sydney and Melbourne – often reported similar vegetation patterns in places such as Yass, Bredalbane, Goulburn and Bathurst (e.g. October 30, 1836, Mitchell 1838). For instance, on the Bathurst Plains in the central Tablelands of NSW, also drawing on early historic accounts, Butzer and Helgren (2005) concluded that grasslands were more extensive than previous reconstructions, and that frequent fire (likely anthropogenic) influenced grass/tree boundaries. In contrast, on the VVP west of Melbourne, archival research suggests the extent of grasslands may have been exaggerated in state wide reconstructions. Nearly half of all historic annotations collated from the newer volcanics (41%) refer to trees and wooded vegetation (see Foreman 2016), and the only known localised fine–scale reconstruction from this region (a 648 km^2 area near Werribee; Sinclair and Atchison 2012) shows ~12% or >61 km^2 less grassland, greater landscape variegation and much non–alignment of grass/tree boundaries c.f. the EVC reconstruction.

The 'archival benchmark' or historic baseline presented here in general corroborates the inverse–texture hypothesis, which provides a general explanation of the expected patterns of woody biomass in this part of the continent. The EVC reconstruction portrays a sharp transition above a 400 mm (mean annual rainfall) 'threshold', where woody vegetation is completely dominant irrespective of soil type and with grassland more–or–less entirely dropping out above 450 mm. While the EVC reconstruction aligns with the inverse texture effect in northern Victoria, there are numerous major anomalies elsewhere – such as the VVP west of Melbourne – that require further explanation (also see critique of Foreman 1996 and Lunt 1997 in Foreman 2016). The significance of the divergence between the EVC pattern c.f. the multi–bioregional historic benchmark presented here, is that it suggests these anomalies may not be the rare exceptions they are often made out to be (e.g. Western Port grasslands; Cook and Yugovic 2003), with regional factors potentially overriding the broader drivers of vegetation patterns much more often than reflected in previous reconstructions.

Alongside the conclusion that the inverse texture effect applies throughout the inland arid zone of Australia, Fensham *et al.* (2015) also report that this effect is suddenly reversed in mesic hinterlands in the east and north and across much of the south (as illustrated by the EVC reconstruction; Figure 3). In these regions "*the superior moisture–holding capacity and fertility of clays relative to sands allows for the development of higher woody biomass*." (Fensham *et al.* 2015). The historic tree/grass boundary mapping suggests this 'reversal' may not be as pronounced or as dramatic as represented in these broader scale studies. Analysis of fine–scale soil surface texture patterns across the irrigation regions of the Victorian Riverina (c.f. the coarse–scale spatial units used in Fensham *et al.* 2015) shows dramatic underestimates of clay soil extent in the continental coverage (–40% or >1,000 km^2 – see Foreman in prep). This, combined with a vegetation reconstruction inadequately corroborated by historic data, could have resulted in major sampling errors in the relative estimates of reconstructed mean above–ground woody biomass (t/ha) at the bioregional scale (i.e. both the errors (1) 'pick sand when clay', and (2) 'pick woody when grassland'), and would have contributed to significantly smoothing out the clay 'bump' for mesic hinterlands; see Fig. 1 in Fensham *et al.* (2015). For instance, this could mask a gradual transition zone into mesic regions (instead of a 'reversal' switch or tipping point threshold) whereby tree mortality is increasingly driven by extreme (c.f. seasonal) climate–edaphic effects and/or 'top–down' processes such as fire, even though it can be difficult to hold eucalypts back with burning in some environments (Fensham and Fairfax 2006).

Foreman (2016) argued that the Pleistocene and Holocene relict hypotheses (Fensham and Fairfax 1996) would be applicable to mesic grasslands of south–eastern Australia as eucalypts could be eliminated (or greatly retarded) in productive lowland plains where they exhibit little lignotuber development and effectively function like obligate seeders, and young seedlings are vulnerable to frequent intense summer burning if within the 'flame zone'. Testing the 'woody invasion following cessation of burning' and 'inhibited woody invasion with re–introduction of fire' hypotheses (see Foreman 2016), by comparing carefully selected sites, would help establish fire mortality of tree (eucalypt) seedlings as one of the key mechanisms of treelessness in these grasslands. Further evidence for the role of fire in shaping the phytoecology of these grasslands could be seen in the functional and genetic structure of the woody dominants of open grassy savannahs – especially in the highest rainfall zones (such as the VVP and Gippsland Plains). Here, populations of non-serotinous resprouters such as Honeysuckle (*Banksia marginata*), could be the result of selection due to frequent fire regimes (see Radeloff *et al.* 2004; Lamont *et al.* 2013).

Under the inverse texture effect, it could be argued that the incongruence between the distribution pattern of pre–European grasslands and that predicted from broad–scale climate–edaphic models may be resolved by fine–scale edaphic coverages. Careful analysis of the edaphic environment across historic grass/tree boundaries (using fine–scale soil maps from throughout the irrigation region of the Victoria Riverina) will be a major emphasis for future study (see Foreman in prep) and help reveal important regional and local nuances in phytoecology, including whether the fine–scale distribution and dynamics of temperate grasslands was at least in part due to fire (see Test #4 in Foreman 2016).

Nature of historic 'plains'

The historic record in this study paints a more nuanced picture of the grasslands than is typically gained from historic studies (e.g. Connor 1966; Fensham 1989; Fensham and Fairfax 1997; Butzer and Helgren 2005; Sinclair and Atchison 2012), although it should be kept in mind that floristic description was constrained by the incipient state of Australian plant taxonomy in these early decades. Nevertheless, instead of the typically brief, generic physiognomic descriptors at particular locations (i.e. growth form, structure, and cover), aggregation of selected records from multiple observers – in different years and seasons – helped build a picture of a dynamic and diverse ecosystem composed of multiple life–forms. These were not homogeneous, species–poor, and always grass–dominant environments as the term 'grassland' might suggest. The most common records were for grasses and geophytes (and other herbaceous wildflowers) and the journals often describe open 'plains' ablaze with colour. Remarkably, records about 'Murnong' – sometimes apparently the most dominant life–form over large areas – were common, especially on or near locations described as 'plains' by observers. Gott (1983) details 55 separate Aboriginal names for 'Murnong' from at least 94 records in the historic archives mostly in Victoria, but acknowledges that some ethnographic references to 'yams' were ambiguous and likely included geophytic monocots, and other tuberous dicots such as *Geranium*, *Convolvulus* and *Clematis*. The floristically diverse system that emerges from the historic records also accords with the ethnographic record (Gott 1982, 1990, 1993) and the systematic study of refugia (e.g. Stuwe and Parsons 1977; Stuwe 1986; Kirkpatrick *et al.* 1988, 1995, McDougall and Kirkpatrick 1993; Lunt 1997). Meanwhile, in the drier north, along with *Themeda* being replaced by succulent life–forms and other grasses adapted to the semi–arid climate, there is also an apparent absence of broad–acre burning.

Although the distinctive pan–palaeotropical Kangaroo Grass would have naturally attracted European attention (as it was described in 1775 and likely valued from earlier British colonies in India, Africa and Malaysia; e.g. Hepper and Friis 1996), its ubiquity in the early descriptions would still have reflected it's widespread distribution in mesic regions, in much the same way that it frequently occurs in the best refugia today (Williams *et al.* 2015). However, collectively, the historic accounts suggest these grasslands were not monocultures but more complex systems with a wide range of interstitial forbs, patches of various smaller shrubs/subshrubs, and many fire–tolerant, suckering non–eucalypt small trees such as Blackwood and Honeysuckle (Table 3). The early accounts in the Upper Campaspe 'plains', in particular, also suggests dramatic seasonal biomass dynamics; a regular sequential functional regime of 'fire *then* forbs (e.g. Murnong) *then Themeda.*' Even though the evidence assembled here from the historic archives is inferential, there is a distinct trace of frequent fire and people in the nature of these grassy landscapes. As Lunt (1998) mused in relation to the role of frequent burning influencing century–scale change in *Themeda* grasslands: '*it is difficult to conceive of alternative processes which might have acted across broad areas.*' However, can we rely on the historic archives to reveal a direct and informed understanding of fire use in traditional Aboriginal society in alignment with the implied phytoecological evidence?

Evidence of the targeted, purposeful and frequent use of fire by Aborigines from historical journals

Although broad–acre fires were commonly reported more–or–less across the region and throughout much of the year, only one was likely due to lightning and very few were explicitly linked to Aborigines by the observers as likely examples of traditional landscape burning. However, this apparent paucity of traditional burning observations is likely misleading, and a closer examination of the evidence reveals a more complex picture. On the one hand, a significant proportion of broad–acre fires (10) were, in fact, a reaction to European arrival, while on the other hand, the limits of observation, the incipient impacts of colonisation and European ignorance meant that the many fires reported could not readily be classified in terms of scale, ignition or (Aboriginal) purpose. Thus, it is possible the observers reported up to 58 broad–acre Aboriginal fires, up to 48 of which could have been examples of traditional landscape burning practices.

It is important to distinguish reactive burning because it is likely this was a novel use of fire spontaneously deployed as a defensive or offensive reaction to the threat of European intrusion and possibly in contrast to long established practices. For instance, close reading of Hume and Hovell's accounts of 'current' fires in December 1824 (Andrews 1981) suggest they were more likely reactive – even though the explorers themselves believed they were witnessing 'traditional' burning. Historian, Henry Reynolds (1982; 1987), cites fire as a "*potent* [pyro–guerrilla warfare] *weapon*" deployed by Aborigines on the frontier as part of the systemic and sustained resistance to colonisation, often misinterpreted or dismissed by historians (see Gammage 2011 pg. 160).

It makes sense that reactive burning was prominent in the historic record, albeit often under–recognised. Similarly, European ignorance – along with the unfolding disintegration of traditional society – also likely contributed to the under–recognition of Aboriginal agency in the remaining reported broad–acre fires (up to 48). The overlanders, in particular, struggled to understand traditional society and consequently, the reader is left to speculate about Aboriginal agency from clues in their fragmentary accounts. For instance, all the circumstantial evidence in Walker's (1838) earlier cited report of burning on the Upper Campaspe 'plains' points to Aboriginal agency rather than background wildfire as the most likely explanation for unclassified broad–acre fires.

Incidences of broad–acre fires explicitly attributed to non–reactive Aboriginal ignition were rare and only reported by Robinson – on the basis of hearsay from others (e.g. February 11 & 20, 1841; Clark 2014) or where Robinson himself either directly observed ignition, presumed ignition by association, or learned of it through conversation with the Aborigines. It is perhaps no coincidence that it was only Robinson who explicitly recorded the link between Aborigines and traditional burning, as he was the only early observer directly concerned with Aboriginal interests under the auspice of the Protectorate (Christie 1979).

Interpretation of traditional practices from early records is problematic because European intrusion was profoundly disruptive, inciting frontier–wide conflict and suppressing traditional practices (amongst other things), and Europeans were ill–equipped to understand and interpret the impact of Aboriginal burning on the landscape. The records provide some evidence of burning targeted towards 'plains' as well as a seasonal bias towards summer into mid–Autumn, but little more. Synthesis of the earliest historic observations in this case study really only tells us that Aboriginal burning was occurring (including reactive fires), but likely under reported due to scant records, and the misunderstandings and prejudices of the intruders. While few observers were aware enough to 'see' traditional burning while it was still being practiced, there is evidence of fires in the collective accounts that could have been such practices, and which has revealed some useful insights. Nevertheless, there remains a need for more historic case studies, based on the earliest and most reliable primary observations (see Foreman in review), to clearly describe the targeted, purposeful and frequent use of fire by Aborigines inferred in the accounts studied here.

Conclusion

This study assembled the first multi–bioregional reconstruction of lowland temperate grasslands derived from hundreds of historic survey plans that were well–corroborated by the earliest Europeans who journaled their routes and observations. The resulting archival benchmark aligns poorly with existing reconstructions based on climate–edaphic ('bottom–up') assumptions, and further fine–scale edaphic analysis could help pinpoint areas reflecting the overriding influence of disturbance such as Aboriginal burning. The results lend support to treelessness driven by complex 'bottom–up' and 'top–down' process interactions and that grassland reconstructions should be extensively corroborated with the historic archives, if not derived exclusively from them. Consequently, the results support Hypothesis #1 (Foreman 2016): that 'Corroborated historic records of grasslands [occur] in areas where trees are expected (>400mm per year).'

The historic record shows that these grasslands were not simple, grass–dominant environments, but a rather more dynamic and diverse ecosystem composed of multiple life–forms including interstitial forbs like the edible geophyte Yam Daisy ("Murnong"), subshrubs, and fire–tolerant small trees. While there is a distinct trace of frequent fire and people in the historic nature of these grassy landscapes, and there is evidence of fires in the collective historic accounts that could have been broad–acre Aboriginal burning, there remains a need for more in–depth and reliable historic case studies to clearly describe the targeted, purposeful and frequent use of fire by Aborigines (Test #9; Foreman 2016) than is inferred in the accounts studied here.

Acknowledgements

This paper was developed from part of a presentation at the 2017 Ecological Society of Australia conference: 'Multiple evidence of Aboriginal burning in lowland, mesic grassy ecosystems of south–eastern Australia'. Appreciation is extended to Dr. John Morgan (Ecology, Environment and Evolution) of La Trobe University, Doug Benson and an anonymous referee for helpful comments on the original manuscript. Thanks also to Dr. Pete Green and Associate Professor John Webb (Ecology, Environment and Evolution) for their support. This research did not receive any specific funding.

Conflicts of Interest

The author declares no conflicts of interest.

References

Andrews AEJ (Ed) (1981) 'Hume and Hovell 1824.' (Blubber Head Press: Hobart)

Attwood B (2017) The Good Country. The Djadja Wurrung, the Settlers and the Protectors. Monash University Publishing, Clayton, Australia.

Batek MJ, Rebertus AJ, Schroeder WA, Haithcoat TL, Compas E, Guyette RP (1999) Reconstruction of early nineteenth-century vegetation and fire regimes in the Missouri Ozarks. *Journal of Biogeography*, 26: 397–412.

Bickford S, Mackey B (2004) Reconstructing pre–impact vegetation cover in modified landscapes using environmental modelling, historical surveys and remnant vegetation data: a case study in the Fleurieu Peninsula, South Australia. *Journal of Biogeography* 31, 787–805.

Hovell WH, Hume H (1831) In Bland W (1965) 'Journey of discovery to Port Phillip, New South Wales; Messrs W.H. Hovell and Hamilton Hume in 1824 and 1825, Sydney: A. Hill, Printer, George Street.' Australian Facsimile Edition No. 12. (Libraries Board of South Australia: Adelaide).

Bolliger J, Schulte LA, Burrows SN, Sickley TA, Mladenoff DJ (2004) Assessing ecological restoration potentials of Wisconsin (USA) using historical landscape reconstructions. *Restoration Ecology*, 12(1): 124–142.

Bond WJ (2005) Large parts of the world are brown or black: a different view on the 'Green World' hypothesis. *Journal of Vegetation Science* 16, 261–66.

Bond WJ (2008) What Limits Trees in C4 Grasslands and Savannas? *Annual Review of Ecology, Evolution, and Systematics* 39, 641–59.

Bond WJ, Midgley GF, Woodward FI (2003) What controls South African vegetation: climate or fire? *South African Journal of Botany* 69, 79–91.

Bond WJ, Woodward FI, Midgley GF (2005) The global distribution of ecosystems in a world without fire. New Phytologist 165, 525–538.

Bowman DMJS (1998) Tansley review no. 101: the impact of Aboriginal landscape burning on the Australian biota. *New Phytologist* 140, 385–410.

Bowman DMJS, Brown MJ (1986) Bushfire in Tasmania: a botanical approach to anthropological questions. *Archaeology in Oceania* 21, 166–171.

Bowman DMJS, Murphy BP, Burrows GE, Crisp MD (2012) Fire regimes and the evolution of the Australia biota. In 'Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world'. (Eds RA Bradstock, AM Gill, RJ Williams) pp. 27–48. (CSIRO Publishing: Melbourne)

Bowman DMJS, Wood SW, Neyland D, Sanders GJ, Prior LD (2013) Contracting Tasmanian montane grasslands within a forest matrix is consistent with cessation of Aboriginal fire management. *Austral Ecology* 38, 627–638.

Bromberg KD, Bertness MD (2005) Reconstructing New England Salt Marsh Losses Using Historical Maps. *Estuaries* 28(6), 823–832.

Brown D (1998) Mapping Historical Forest Types in Baraga County Michigan, USA as Fuzzy Sets. *Plant Ecology* 134, 97–111.

Butler DW, Fairfax RJ, Fensham RJ (2006) Impacts of tree invasion on floristic composition of subtropical grasslands on the Bunya Mountains, Australia. *Australian Journal of Botany* 54, 261–270.

Butler DW, Fensham RJ, Murphy BP, Haberle SG, Bury SJ, Bowman DMJS (2014) Aborigine–managed forest, savanna and grassland: biome switching in montane eastern Australia. *Journal of Biogeography* 41, 1492–1505.

Butzer KW, Helgren DM (2005) Livestock, Land Cover, and Environmental History: The Tablelands of New South Wales, Australia, 1820–1920, *Annals of the Association of American Geographers* 95, 80–111.

Cahir F, McMaster S (2018) Fire in Aboriginal south–eastern Australia. Chapter 7 IN Aboriginal Biocultural Knowledge in South–eastern Australia – Perspectives of early colonists. Cahir, F., Clark, I.D., Clarke, P.A. (CSIRO Publishing: Clayton South)

Cahir F, McMaster S, Clark I, Kerin K, Wright W (2016) *Winda Lingo Parugoneit* or Why Set the Bush [On] Fire? Fire and Victorian Aboriginal People on the Colonial Frontier, Australian Historical Studies 47, 225–240.

Christie MF (1979) 'Aborigines in colonia Victoria 1835–86.' (Sydney University Press: Sydney)

Clark ID (1990) 'Aboriginal languages and clans: an historical atlas of western and central Victoria, 1800–1900.' Monash Publications in Geography No. 37. (Department of Geography, Monash University: Melbourne)

Clark ID (Ed) (2014) 'The journals of George Augustus Robertson, Chief Protector, Port Phillip Aboriginal Protectorate, Volume Two: 1 October 1840 – 31 August 1841.' Revised Edition.

Clark ID (Ed.) (1988) 'The Port Phillip journals of George Augustus Robertson: 8 March – 7 April 1842 and 18 March – 29 April 1843.' Monash publications in geography no. 34. (Department of Geography, Monash University: Melbourne)

Clark RL (1983) Pollen and charcoal evidence for the effects of Aboriginal burning on the vegetation of Australia. *Archaeology in Oceania* 18, 32–37.

Connor DJ (1966) Vegetation studies in North–west Victoria II. The Horsham area. *Proceedings of the Royal Society of Victoria* 79, 637–653.

Costin AB (1954) 'A study of the ecosystems of the Monaro region of New South Wales: with special reference to soil erosion.' (AH Pettifer, Government Printer: Sydney)

Cousins SA (2001) Analysis of land–cover transitions based on 17th and 18th century cadastral maps and aerial photographs. *Landscape Ecology* 16: 41–54.

Croft T (1999) 'Pre–European settlement floristic vegetation mapping for the south east region.' Environmental Information and Analysis, Department for Environment and Heritage. (Government of South Australia: Adelaide)

Downey J (1863) Parishes of Dargalong and Molka, Murray District [cartographic material]; surveyed by John Downey, Contract Surveyor, July 1863 ; photo–lithographed at the Department of Lands and Survey, Melbourne, by J. Noone. Source: State Library of Victoria.

Eccleston GC (1988) Major Mitchell's 1836 Australia Felix expedition: a report on a proposal for a 'Major Mitchell long distance track.' Citizens Council for Victoria's 150th Anniversary Celebrations, Gardens and Environment Committee. (La Trobe University: Bundoora)

Ellis RC (1985) The relationship among eucalypt forest, grassland and rainforest in a highland area of north–eastern Tasmania. *Australian Journal of Ecology* 10, 297–314.

Everett A (1869) 'Victoria [cartographic material] : distribution of forest trees / compiled by Arthur Everett from the record maps in the Office of the Surveyor General, and other authentic sources, under the direction of R. Brough Smyth ; engraved by William Slight.' (Minister of Mines for the State Forests Board: Melbourne)

Fensham RJ (1989) The pre–European vegetation of the Midlands, Tasmania: a floristic and historical analysis of vegetation patterns. *Journal of Biogeography* 16, 29–45.

Fensham RJ (1997) Aboriginal fire regimes in Queensland, Australia: analysis of the explorers' record. *Journal of* Biogeography 24, 11–22.

Fensham RJ, Butler DW, Foley J (2015) How does clay constrain woody biomass in drylands? *Global Ecology and Biogeography* 24, 950–958.

Fensham RJ, Fairfax RJ (1996) The disappearing grassy balds of the Bunya Mountains, south–eastern Queensland. *Australian Journal of Botany* 44, 543–558.

Fensham RJ, Fairfax RJ (1997) The use of the land survey record to reconstruct pre□European vegetation patterns in the Darling Downs, Queensland, Australia. *Journal of Biogeography* 24, 827–836.

Fensham RJ, Fairfax RJ (2006) Can burning restrict eucalypt invasion non grassy balds? Austral Ecology 31, 317–325.

Fensham RJ, Fairfax RJ (2007) Drought–related tree death of savanna eucalypts: species susceptibility, soil conditions and root architecture. *Journal of Vegetation Science* 18, 71–80.

Foreman PW (1996) Ecology of native grasslands of Victoria's northern Riverine Plain. MSc Thesis, La Trobe University, Melbourne.

Foreman PW (2016) A framework for testing the influence of Aboriginal burning on grassy ecosystems in lowland, mesic south–eastern Australia. *Australian Journal of Botany* 64, 626–642.

Foreman PW (in review) Aboriginal burning in the grassy ecosystems of lowland, mesic south–eastern Australia: The special case of the Western Port journey. *Australian Journal of Botany*.

Foreman PW (in prep) Temperate grassland distribution in south–eastern Australia not aligned with soil boundaries but linked to proxys of Aboriginal habitation.

Gammage B (2011) 'The biggest estate on earth: how Aborigines made Australia.' (Allen and Unwin: Sydney)

Gimmi U, Lachat T, Bürgi M (2011) Reconstructing the collapse of wetland networks in the Swiss lowlands 1850–2000. *Landscape Ecology* 26, 1071–1083.

Gott B (1982) Ecology of root use by the aborigines of southern Australia. *Archaeology in Oceania* 17, 59–67.

Gott B (1983) Murnong – Microseris scapigera. A study of a staple food of Victorian Aborigines. Australian Aboriginal Studies, 1983, 2–17.

Gott B (1990) 'VICUSE' file – unpublished database. Copy lodged at the National Herbarium of Victoria, Melbourne.

Gott B (1993) Use of Victorian plants by Koories. 'Flora of Victoria', Vol. 1 (ed. by Foreman DB, Walsh NG), pp. 195–211. (Inkata Press: Melbourne).

Hallam SJ (1989) Plant usage and management in southwest Australian Societies. In 'Foraging and farming: the evolution of plant exploitation'. (Eds DR Harris, GC Hillman) pp. 136–151. (Unwin Hyman: London)

Hawdon J (1952) 'The journal of a journey from New South Wales to Adelaide (the capital of South Australia) Performed in 1838 by Mr. Joseph Hawdon.' (Georgian House: Melbourne)

He HS, Dey D, Fan X, Hooten MB, Kabrick J, Wikle C, Fan Z (2007) Mapping Pre–European Settlement Vegetation at Fine Resolutions Using a Hierarchical Bayesian Model and GIS. *Plant Ecology* 191, 85–94.

Hepper FN, Friis I (1996) The plants of Pehr Forsskål's Flora Aegyptiaco–Arabica. In: van der Maesen L.J.G., van der Burgt X.M., van Medenbach de Rooy J.M. (eds) The Biodiversity of African Plants. Springer, Dordrecht.

Hirota M, Holmgren M, Van Nes EH, Scheffer M (2011) Global Resilience of Tropical Forest and Savanna to Critical Transitions. *Science* 334, 232.

Hoddle R (1853) 'Plan of the general survey from the town of Malmsbury to the Porcupine Inn, from the sources of Forest Creek to Golden Point [cartographic material] : shewing the Alexandrian Range, also Sawpit Gully Bendigo and Bullocks Creek / copied by C.A.C. Bayly, Draftsman, 1862.' (Surveyor General's Department of the Colony of Victoria: Melbourne)

House J, Archer S, Breshears DD, Scholes RJ, Tree–Grass Interaction Participants NCEAS (2003) Conundrums in mixed woody–herbaceous plant systems. *Journal of Biogeography* 30, 1763–1777.

Jacoby SK, Benwell GL (1989) The Formation of the Victorian Parish System; Part A: The Origins and Instructions. The Australian Surveyor 34, 655–673.

Jacoby SK, Benwell GL (1990) The Formation of the Victorian Parish System; Part B: Implementation. The Australian Surveyor 35, 5–18.

Jones R (1969) Fire–stick farming. *Australian Natural History* 16, 224–228.

Karskens GE (2019) 'Fire in the forests? Exploring the human–ecological history of Australia's first frontier' *Environment and History* 25, 391–419(29).

Keith, D (2004) 'Ocean shores to desert dunes: the native vegetation of New South Wales and the ACT.' (Department of Environment and Conservation: Hurstville)

Kirkpatrick J, Gilfedder L, Fensham R (1988) 'City parks and cemeteries: Tasmania's remnant grasslands and grassy woodlands.' (Tasmanian Conservation Trust Inc.: Hobart)

Kirkpatrick JB, McDougall K, Hyde M (1995) 'Australia's most threatened ecosystems: the south–eastern lowland native grasslands.' (World Wide Fund for Nature: Sydney)

Knight RI (2002) Estimating the pre–European extent of vegetation communities in Tasmania. Report to the Department of Primary Industries, Water & Environment, Hobart.

Lamont BB, He T, Downes KS (2013) Adaptive responses to directional trait selection in the Miocene enabled Cape proteas to colonize the savanna grasslands. *Evolution and Ecology* 27, 1099–1115.

Lehmann CE, Anderson TM, Sankaran M, Higgins SI, Archibald S, *et al.* (2014) Savanna vegetation–fire climate relationships differ among continents. *Science* 343(6170), 548–52.

Lunt ID (1997) The Distribution and Environmental Relationships of Native Grasslands on the Lowland Gippsland Plain, Victoria: an Historical Study. *Australian Geographical Studies* 35, 140–152.

Lunt ID (1998) Two hundred years of land–use and vegetation change in a remnant coastal woodland in southern Australia. *Australian Journal of Botany* 46, 629–647.

Lunt ID (2002) Grazed, burnt and cleared: how ecologists have studied century–scale vegetation changes in Australia. *Australian Journal of Botany* 50, 391–407.

McDougall K, Kirkpatrick J (Eds) (1993) Conservation of Lowland Native Grasslands in South–eastern Australia. Worldwide Fund for Nature, Sydney, NSW.

McIntyre S, Hobbs R (1999) A framework for conceptualizing human effects on landscapes and its relevance to management and research models. *Conservation Biology* 13, 1282–1292.

Mills K (1988) The clearing of the Illawarra rainforests: problems in reconstructing Pre-European vegetation patterns, *Australian Geographer* 19(2), 230–240.

Mitchell TL (1838) 'Three expeditions into the interior of eastern Australia with descriptions of the recently explored region of Australia Felix, and of the present colony of NSW by T.L. Mitchell.' Vol. 2. First edition published in 1838. London: T. & W. Boone.' Facsimile Edition 2011 (Cambridge University Press: New York)

Mollison AF (1980) 'An overlanding diary: April–December, 1837, from Uriara station, on the Murrumbidgee, to Port Phillip, Victoria. Edited with notes by Randell JO.' (Mast Gully Press: Melbourne)

Moore CWE (1953) The vegetation of the south–eastern Riverina. I. The climax communities. *Australian Journal of Botany* 1, 485–547.

Morgan JW, Fensham RJ, Godfree R, Foreman PW (2017) Australian tussock grasslands. In 'Australian vegetation'. 3rd edn. (Ed. D Keith) (CSIRO Publishing: Melbourne)

NVIS (2018) National Vegetation Information System Version 5.1. Department of the Environment and Energy, Canberra. https://www.environment.gov.au/land/native–vegetation/national–vegetation–information–system/data–products#key51

Parkes D, Newell G, Cheal D (2003) Assessing the quality of native vegetation: the 'habitat hectares' approach. *Ecological Management and Restoration* 4, S29–S38.

Polis GA (1999) Why are parts of the world green? Multiple factors control productivity and the distribution of biomes. *Oikos* 86, 3–15.

Presland G (Ed) (1977) Journals of George Augustus Robinson January – March 1840. Edited with an Introduction by G. Presland Second Edition. Records of the Victorian Archaeological Survey No. 5 (Ministry for Conservation: Melbourne)

Radeloff VC, Mladenoff DJ, Guriesa RP, Boyceb MS (2004) Spatial patterns of cone serotiny in *Pinus banksiana* in relation to fire disturbance. *Forest Ecology and Management* 189, 133–141.

Ratajczak Z, Nippert JB (2012) Comment on "Global Resilience of Tropical Forest and Savanna to Critical Transitions." *Science* 336, 541.

Reynolds H (1982) 'The other side of the frontier: Aboriginal resistance to the European invasion of Australia.' (Penguin: Ringwood)

Reynolds H (1987) 'Frontier: Aborigines, Settlers and Land.' (Allen and Unwin: Sydney)

Sankaran M, Hanan NP, Scholes RJ, Ratnam J, Augustine DJ, *et al.* (2005) Determinants of woody cover in African savannas. *Nature* 438, 846–849.

Sankaran M, Ratnam J, Hanan N (2008) Woody cover in African savannas: the role of resources, fire and herbivory. *Global Ecology and Biogeography* 17, 236–245.

Silcock JL (2014) Degraded or just dusty?: 150 years of ecological change in inland eastern Australia. A thesis submitted for the degree of Doctor of Philosophy at The University of Queensland, School of Biological Sciences, Brisbane.

Silcock JL, Piddocke TP, Fensham RJ (2013) Illuminating the dawn of pastoralism: evaluating the record of European explorers to inform landscape change. *Biological Conservation* 159, 321–331.

Silcock JL, Fensham RJ (2019) Degraded or Just Dusty? Examining Ecological Change in Arid Lands. *Bioscience* 69, 508–522.

Sinclair SJ, Atchison K (2012) The pre–colonial distribution of grasslands, woodlands and forests on the Werribee plains, Victoria. *Cunninghamia* 12, 213–227.

Stockton J (1982) Fires by the seaside: historic Vegetation changes in northwestern Tasmania. *Papers and Proceedings of the Royal Society of Tasmania* 116, 53–66.

Stuwe J (1986) 'An assessment of the conservation status of native grasslands on the Western Plains, Victoria and sites of botanical significance.' (Department of Conservation, Forests and Lands: Melbourne)

Stuwe J, Parsons R (1977) *Themeda australis* grasslands on the Basalt Plains, Victoria: floristics and management effects. *Australian Journal of Ecology* 2, 467–476.

Swetnam TW, Allen CD, Betancourt JL (1999) Applied historical ecology: using the past to manage the future. *Ecological Applications* 9, 1189–1206.

Thackway R, Lesslie R (2006) Reporting vegetation condition using the Vegetation Assets, States and Transitions (VAST) framework. *Ecological Management and Restoration* 7, S53–S62.

Van Dyke E, Wasson K (2005) Historical ecology of a central California estuary: 150 years of habitat change. *Estuaries* 28, 173–189.

Van Nes EH, Holmgren M, Hirota M, Scheffer M (2012) Response to Comment on "Global Resilience of Tropical Forest and Savanna to Critical Transitions." *Science* 336, 541–d

Walker T (1838) 'A month in the bush of Australia: Journal of one of a party of gentlemen who recently travelled from Sydney to Port Philip with some remarks on the present state of the farming establishments and society in the settled parts of the Argyle country. Loddon: Cross.' Australian Facsimile Edition No. 114 (1965) (Libraries Board of South Australia: Adelaide)

Wedge JH (1851) GOULB 22 [microform] – Goulburn River & Nine Mile Creek or Pranjip Creek circa. 1851, covering the Arcadia — Bunganail — Dargalong – Molka parishes produced by surveyor John Helder Wedge. (Surveyor General's Department of the Colony of Victoria: Melbourne)

Whittaker RH (1975) 'Communities and Ecosystems' Second Edition (Macmillan: New York)

Williams NSG, Marshall A, Morgan JW (2015) 'Land of sweeping plains: managing and restoring the native grasslands of south–eastern Australia' (CSIRO Publishing: Melbourne)

Woodgate P, Black P (1988) 'Forest cover changes in Victoria 1868–1987.' (Conservation, Forests and Lands: Melbourne)

Manuscript accepted 13 May 2020